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AN ANALYSIS OF AIR FORCE AVIONIC TEST STATION UTILIZATION USING--ETC(U)

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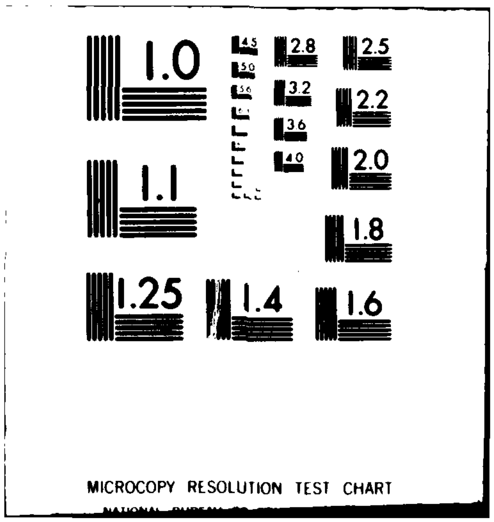
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ABSTRACT

James Russell Lowell, M.S.E., Arizona State University, December, 1979. An Analysis of Air Force Avionic Test Station Utilization Using Q-GERT Modeling and Simulation.

Air Force managers must determine avionic maintenance support resource levels prior to employment of the weapon system associated with such support. A need exists for a method by which probable maintenance support requirements may be evaluated so that resource allocation may be accomplished with confidence. The objective of this report is to show that Graphical Evaluation and Review Technique with Queueing (Q-GERT) simulation can be used to evaluate avionic maintenance support systems. And, that simulation analysis can provide data for avionic maintenance resource allocation.

This report demonstrates the use of Q-GERT to: model an Air Force avionic maintenance system; evaluate the maintenance system through simulation; determine maintenance resource requirements; and, aid management with day-to-day decisions. A Q-GERT network model is developed and translated into computer input format. Simulation of this model is accomplished to provide data for analysis. Analysis illustrates the use of this method as an aid to Command level and Base level decision makers.

Results of this analysis leads to the conclusion that Q-GERT can be used to answer critical questions concerning the availability of avionic maintenance support resources.

B

AN ANALYSIS OF AIR FORCE AVIONIC

TEST STATION UTILIZATION USING

Q-GERT MODELING AND SIMULATION

by

James Russell Lowell

AN ENGINEERING REPORT PRESENTED IN

PARTIAL FULFILLMENT OF THE REQUIREMENTS

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I. INTRODUCTION

Assessment of resource requirements and costs associated with the support of flying activities in various United States Air Force (USAF) organizations is a continuing problem. As new aircraft systems and subsystems enter the inventory, there exists a recurring need for reliable estimates of maintenance resource requirements to activate, maintain, and deploy the emerging system. Such estimates aid USAF managers in allocating maintenance resources to insure mission capability in a timely manner [8].

Background

A method presently used for such evaluations is the Logistics Composite Model (LCOM) simulation technique. With the LCOM simulation language, USAF base level aircraft maintenance and support activities are modeled [10, 11]. Simulation with such a model has been used successfully to determine maintenance manpower requirements to support specified levels of flying activities for several tactical weapon systems (4).

Air Force Test and Evaluation Center (AFTEC) analysis using LCOM has extended the use of LCOM to include assessment of the sensitivity of sortie generation capability to: manpower; spare parts and support equipment levels; reliability/maintainability parameters; and Avionic Intermediate Shop (AIS) test station availability. Although successful,

because of the complexity of LCOM, modeling and analysis of AIS becomes very time consuming and expensive. Consequently, AFTEC has suggested a research effort to develop a procedure by which the Queueing Graphical Evaluation and Review Technique (Q-GERT) may be used for AIS sensitivity analysis [23]. Use of Q-GERT is suggested since its application and simplistic approach will enable more timely and cost effective analysis that will interface well with other ongoing simulation efforts such as LCOM.

Research Problem

A need exists to analyze critical questions concerning test station availability and the effects of that availability on sortie generation capability. AFTEC has suggested the use of Q-GERT as the modeling tool to conduct such analysis [3].

Research Objective

In this research project, the author will use Q-GERT to model and analyze the F-15 AIS. The modeling effort includes identification and definition of the system and system parameters and translation of such parameters into Q-GERT networks. With a basic model constructed, simulation is accomplished and analysis of simulation results is discussed.

Research Scope

The intent of this report is to describe Q-GERT model development and analysis procedures applicaable to USAF weapon system support

evaluation. The F-16 weapon system is used as an example of the application. Although data parameters are realistic, they are not assumed to be accurate. Sortie rate requirements herein are completely fictitious and should not be used for USAF analysis.

Overview

The remainder of this report consists of seven chapters. The Problem Definition chapter describes the system to be simulated and the type of evaluation required. The Q-GERT chapter provides the reader with the Q-GERT network and analysis concepts necessary for the reading of this report. The Modeling chapter details the process by which the defined system is translated into the Q-GERT simulation language. In the Model Validation, Command Level Decision, and Base Level Decisions chapters, discussion of simulation output and the analysis of that output is presented. Finally, the Conclusions and Recommendation chapter summarizes the research findings.

II. PROBLEM DEFINITION

This chapter contains a description of the maintenance system to be modeled. It also identifies and defines evaluation requirements and the parameters used in the evaluation. The description includes pertinent assumptions and the maintenance process.

Sortie Generation

Within the USAF, the flight of an aircraft is termed a sortie. When an aircraft takes off, flys some maneuver, and lands, one sortie is constituted. Many support resources are measured in terms of this sortie since plans are based on how many sorties are required by each aircraft per day to accomplish a desired goal [1, 3]. Sortie requirements of this report are fictitious and should not be considered in any F-16 analysis.

Maintenance Support

Sortie generation is mainly a function of aircraft availability. It is obvious that an aircraft which is unavailable cannot fly, and an aircraft in repair status is considered unavailable. Maintenance support is designed to process aircraft repair in an expedient manner to assure availability. This maintenance is usually accomplished by removing a failed component from an aircraft system and replacing it with a good like item from supply stock. The aircraft is then available

for sortie generation while the failed component is repaired in a maintenance shop.

Aircraft Systems/Subsystems

For purposes of maintenance support, aircraft within the USAF are subdivided into systems. Each system such as Engines, Fuels, and RADAR has specialists trained specifically as maintenanace technicians. Within a system, sybsystems such as Navigational RADAR and Fire Control RADAR exist. These sybsystems are made up of functional component "black boxes" such as computers, control units, transmitters, receivers, etc. Each of these component "black boxes" is referred to as a line replaceable unit (LRU) and constitute the components that are removed and replaced on the aircraft and repaired in the maintenance shop.

Aircraft System Failure

Each system on an aircraft is subject to failure. The Air Force measures these system failures in terms of number of sorties flown. Systems have a failure parameter, assumed to be exponentially distributed, of Mean Sortie Between Maintenance Action (MSBMA) [27]. When an aircraft system fails, one of two methods of aircraft repair occurs. The first of these methods involves the removal of an LRU, the second method does not. Empirical data provides estimates for the probability of LRU removal, given failure of the parent system, for most weapon systems. When a new weapon system with no empirical data is studied,

a comparability study is conducted to extrapolate date from one weapon system to another [27].

Avionic Intermediate Shop

Electronic components of avionic systems, removed from an aircraft, are processed through Avionic Intermediate Shops (AIS) for repair. Modern weapon system AIS rely on an Automatic Test Set with specific test stations designed for functional repair of avionic components.

Upon removal from an aircraft, a given LRU will enter the shop and either go directly to the test station that has repair capability for the unit or it will be placed in waiting status for the availability of the test station. Each test station has the capability to perform diagnostic and fault isolation for several LRUs within a functional group. Systems such as these usually have some sort of adaptors designed to interface the LRU with the test station. Connecting the LRU and interface adaptor to the test station constitutes a set-up procedure.

When a LRU is assigned to a test station there are three basic types of maintenance actions that may be taken; bench check and repair; bench check and no repair required; and not repairable this station [3]. There is an expected task time associated with each of the repair actions that the Air Force has determined to be Lognormally distributed [15]. Upon completion of either repair or no repair required actions, the LRU is returned to supply stock to be used on an aircraft as required. If the LRU is not repairable, it is shipped off-base to a depot repair

facility. This unit is lost to the base supply system until replenishment occurs.

System Modeling Requirements

The object of this research is the analysis of AIS test stations and the effects they have on sortie generation. The following overview, in conjunction with the figure 2-1, details the maintenenace system of interest.

A predetermined sortie generation requirement drives avionic system failures based on MSBMA. When a given system fails, the type of organizational maintenance required on the aircraft is determined probabilistically. If a remove action is required and a LRU spare is available for replacement, the aircraft returns to available status and the failed LRU is routed to the shop. If there is no spare LRU, the LRU removed from the aircraft must be repaired and reinstalled prior to the aircraft becoming available for flight.

A LRU removed from the aircraft is transported to the shop and may either enter awaiting maintenance (AWM) status or go directly to the appropriate test station depending on test station availability. When the test station is available, the LRU repair action is determined probabilistically with the time to repair selected from a Lognormal distribution. The LRU repair action may lead to replenishment of supply stock, repair of an aircraft, or a depot delay depending on the predetermined type of removal for the aircraft or the probabilistic repair action taken.

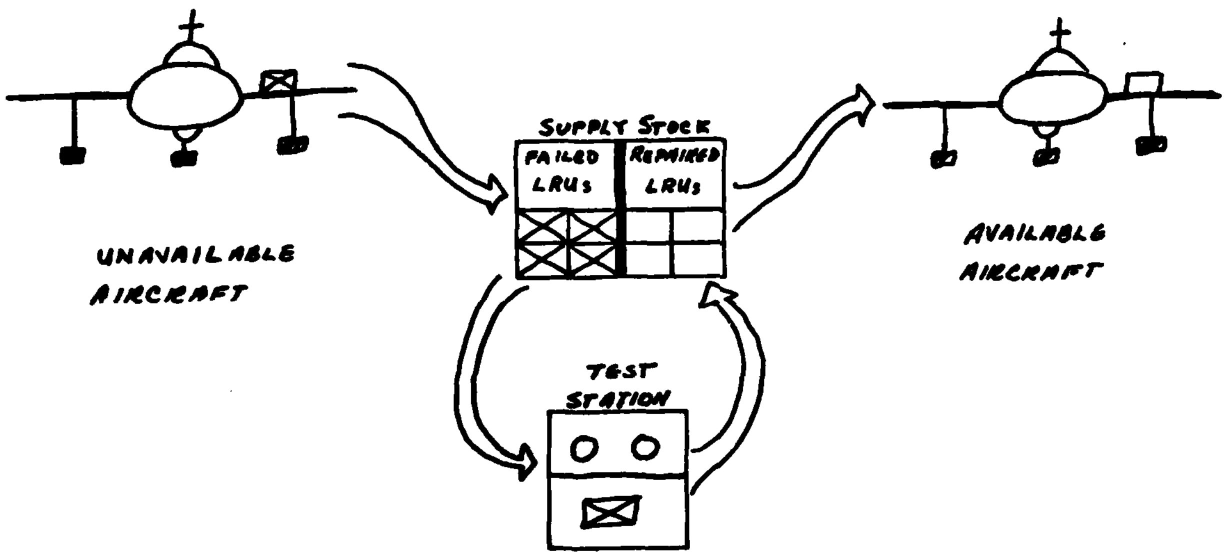


Figure 2-1. Maintenance Repair Cycle

Parameters of Evaluation

Analysis of this system requires that control over attempted or scheduled sorties is available to the analyst. There must also be a method to allow failures based on MSBMA and the probabilities associated with LRU removal given a system failure.

With a LRU flow into the shop initiated, it is necsssary to follow each LRU through the shop process to determine the average total time in the shop, average time in queues, and total number processed. The cumulation of these repair activities will provide a test station utilization statistic.

Iterative simulation over a spectrum of sortie generation rates and the above mentioned statistics will provide the necessary data to determine test station resources required to support given sortie generation rates.

III. Q-GERT MODELING

Development of Q-GERT

The technique used herein is an extension of the GERT simulation models, and GERT model development will be duscussed to summarize the events which lead to Q-GERT. For the reader interested in a detailed treatment, refer to [24, 25, 26].

GERT is a result of an extension of the modeling capabilities of PERT and CPM. Pritsker and Happ [26] developed and defined this "stochastic network" or Graphical Evaluation and Review Technique (GERT) network. Generally, stochastic networks are characterized by:

1. Directed branches representing activities or processes,

2. Each branch is assigned a probability of occurrence and other parameters which describe the distribution of time to traverse the branch,

3. Logical nodes which denote the precedence relationship between the incident and emanating branches of the node, and

4. A realization of the network is a set of branches and nodes which define a path through the network for one experiment [16].

The input at each node may be singular or multiple with AND-type (all incident branches must be realized) or OR-type (only one incident branch must be realized) logic. Logic such as these allow the node to be realized and upon realization of a node, transaction output may be either deterministic or probabilistic. Determine output causes the

release of all branches emanating from a node while probabilistic implies that only one branch is released according to the probabilities of the branch. Such probabilistic selection of branches emanating from a node is mutually exclusive and the sum of probabilities must be unity.

The expanded network logic of GERT allows for network modeling where not all of the paths of the network must be traversed to reach the terminal point. Because of this model enhancement, GERT can be used to model situations where one of many paths will lead to success.

Upon realization of the limitation of GERT as an analytic model, Pritsker developed a simulator called GERTS [25]. This original simulator has been revised several times and each time additional capabilities and improvements in methods of data storage were added [16].

The most recent addition to the GERT family is Q-GERT. The Q implies a capability to formulate queues at nodes designed as Q-nodes. This feature of the model is not new; previous GERT models, particularly GERTS-IIIQ and GERTS QR, had the same capability. The characteristics of Q-GERT that makes it an improved model are that it combines most of the features of all predecessor GERTS models and in addition gives the analyst the flexibility to write and insert "user functions" which follow the general logic of the Fortran based GASP IV simulation language [24].

Summary of Modeling and Notation

The first step in modeling with Q-GERT is drawing a network design of the system to be studied. The graphical model associated with

Q-GERT is basically a means of communicating the process of interest. It also represents the organization and definition of the problem for input to the computer program. Networks establish a means by which the analyst can clearly define the relationship among system components, the parameters of the system, and the decision points and rules within the system. When the network is complete, the analyst may study it and determine, in many cases without the aid of the computer, errors in logic, or flaws in the design of the system. After concluding the network represents the desired system, network notation is readily transformed to computer input form. Experience has shown the network to be an excellent means of explaining the sytem, system parameters and impending analysis of the output to those not well versed in the methods of Operations Research or Systems Analysis.

The network consists of branches representing activities or directional flow paths and nodes representing logical relationships between activities. Transactions representing entities being processed, flow through the network from node to node through the branches as shown in figure 3-1. Each branch has a starting and ending node and transactions that traverse the branch are delayed by the time associated with the activity the branch represents [24, 25]. The times associated with the activity may be selected from several built-in distributions or by a user defined distribution. Each transaction may be assigned attributes that distinguish some characteristic of the entity being modeled. For some node-branch relationships, a transaction's attributes can be used to identify activity parameters or branching

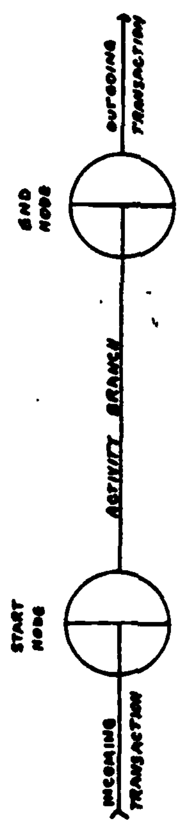


Figure 3-1. Q-GERT Transaction Flow

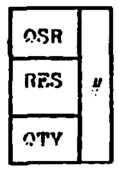
rules. When a transaction reaches a node, the node-type determines disposition of that transaction. Regular nodes are used for deterministic and probabilistic routing. These nodes may also invoke conditional branching, a new feature of Q-GERT. Queue nodes detain or hold a transaction until availability of a service facility, resource, or match criteria release the node. New features of the Q-GERT model that are associated with queue nodes include: select nodes which allow the analyst to define prioritized selection and routing of queue transactions; and, allocate nodes which hold a transaction in the queue until a required resource is available. Nodes that are related to the allocate nodes are: free nodes which release an assigned resource to be allocated upon completion of the activities which entail resource utilization; and, alter nodes which provide a method to increase or decrease the quantity authorized of a given resource [24].

Node and branch symbology used in this report is presented in Table 3-1a through Table 3-1d with a brief explanation of the function of each symbol. The translation of network symbols used herein to computer input form is described in Table 3-2 [24].

When the Q-GERT network has been translated to computer input form, all that remains to be done is simulation and analysis. Free form coding and the ability to visually debug a network are time saving features of the Q-GERT model. If, however, programming errors exist upon initial attempts of simulation, Q-GERT diagnostic messages are

Table 3-1a* Q-GERT Symbols

Definition



QSR is the queue selection rule that will be used to allocate resources.

RES is the resource number that is used to identify the resource type.

QTY is the quantity of resource type RES.

R is the resource type to be released.

N is the number of the resource to be freed.

is the Free node number.

ALL is the allocate node of the resource.

R is the resource type number.

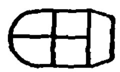
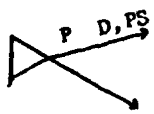
C is the capacity change requested.

is the Alter node number.

ALL is the allocate node of the resource.

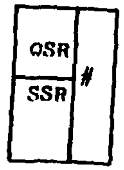
*Extracted from Pritsker [24].

Table 3-1b* Q-Gert Symbols

Symbol	Definition
	A is the attribute number to which a value is to be assigned; if A is specified, add value to attribute A; if A- is specified, subtract. D is the distribution or function type from which assignment value is drawn. PS is the parameter set number.
	Indicates conditional take-first branching from the node.
	Indicates conditional take-all branching from the node.
	If P 1.0, Pis the probability of taking the activity. If P 1, P is an attribute number.

*Extracted from Pritsker [24].

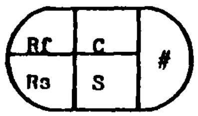
Table 3-1c* Q-GERT Symbols

	Definition
	QSR is the queue selection rule for routing transactions to or from Q nodes. SSR is the server selection rule for deciding which server to make busy if a choice exists. # is the S node number.
	# is the activity number causing nodal modification. n is the node number to be replaced when activity # is completed. m is the node number that will replace node n when activity # is completed.
- - - - - - -	Routing indicator for transaction flow to or from Q nodes to S nodes or Allocate nodes.

*Extracted from Pritsker [24].

Table 3-1d* Q-GERT Symbols

Definition

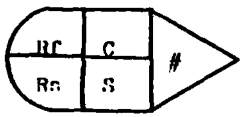


Rf is the number of incoming transactions needed to release the node the first tim.

Rs is the number of incoming transactions needed for all other releases of the node.

C is the criterion for holding the attribute set at a node.

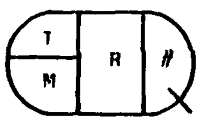
S is the statistics type or marking.



is the node number.

indicates deterministic branching.

indicates probabilistic branching.

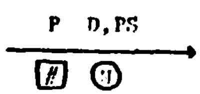


I is the initial number of transactions at the Q node.

M is the maximum number of transactions that the queue can except.

R is the ranking procedure for ordering transactions at the queue.

is the Q node number.



P is the probability of taking the branch.

D is the distribution or function type from which the activity time is drawn.

PS is the parameter set number where the parameters for the activity time are specified.

is the activity number.

(π) is the number of paralles servers associated with the activity.

*Extracted from Pritsker [24].

Table 3-2* Q-GERT Input Format

1	2	3	4	5	6	7	8	9	10
REG/SOU	Node number	Initial number to release	Subsequent number to release	Branching	Marking	Choice criterion			
SIN/STA	Node number	Initial number to release	Subsequent number to release	Branching	Statistics desired	Upper limit of first cell	Width of histogram cell	Choice criterion	
QUE	Node number	Initial number in queue	Capacity of Q-node	Branching	Ranking	Block or node number for balkers	Upper limit of first	Width of histogram cell	Following allocate nodes
SEL	Node number	Queue selection rule	Server selection rule	Choice criterion	Block or node number for balkers	Associated Q-nodes			
VAS	Node number	Attribute number	Distribution type	Parameter set					
PAR	Parameter set number	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Stream number			
ACT	Start node	End node	Distribution of function type	Parameter set or constant	Activity number	Number of parallel servers	Probability of attribute number or order	Condition code	
MOD	Activity number	Node out	Node in						
TRA	Node number								

*Extracted from Pritsker [24].

printed in the output to aid in sumulation debugging. If debugging cannot be accomplished with the aid of these diagnostics, there is a feature of the model that allows nodal and/or event tracing to help locate faulty network logic.

IV. MODEL OF THE SYSTEM

System Definition

The system modeled is similar to the job-shop consisting of a single homogeneous resource. Other resources are considered as always available when the one defined resource is available. There are six types of arrivals (LRUs), each having a Poisson arrival rate modified by a conditional probability [27]. Each arriving LRU transaction enters a queue specified by the type LRU identified by attributes, and no balking occurs. When a test station resource is available, it is allocated to one of the waiting LRU transactions allowing the LRU transaction to continue processing through the repair shop. Each LRU has an exclusive set of service channels with probabilistic routing to repair activities with mean repair times drawn from a Lognormal distribution [15]. As each LRU completes the service activity, the test station resource is freed and made available to be allocated to the next waiting transaction. The completed transaction is routed to a node used as a counter that will fail the test station after a given number of transactions have been processed.

Prior to the shop process described above, an integral portion of the system must be modeled. The arriving LRU transactions represent failed aircraft components with failure rates based on the number of times an aircraft has flown. Thus, the first part of the system must simulate the generation of aircraft and the use of those aircraft to fly sorties to drive system and LRU failures.

Additionally, the total system must include a method to control the amount of time each day that flight and maintenance operations are accomplished and control the number of operating days each week.

Aircraft Generation

Aircraft are generated by the source node. Each aircraft generated is an entity which must have attributes representing avionic systems and all aircraft entering the system will stay in the system. The analyst must decide how many aircraft should be generated to establish flying and failure rates. Most fighter aircraft units have flying squadrons with 24 aircraft assigned [3, 4]. Based upon this knowledge, the example described in this report has 24 aircraft generationed as indicated in figure 4-1.

Source node-1 is realized upon activation of the simulator and the first transaction generated is assigned the value one, to attribute-1. This transaction, due to the conditional take-all branching of the source node, will traverse both paths emanating from the node. As shown, the upper path from node-1 to node-1 has the condition A1.LE.23, which allows transactions with the value of attribute-1, of 23 or less, to traverse the path. Since node-1 is also an increment node, each transaction that causes node realization will have the value of attribute-1, increased by one. When the value of attribute-1 reaches 24, that number of aircraft has been generated since very transaction has also traversed the branch leading to node-2 with condition A1.LE.24.

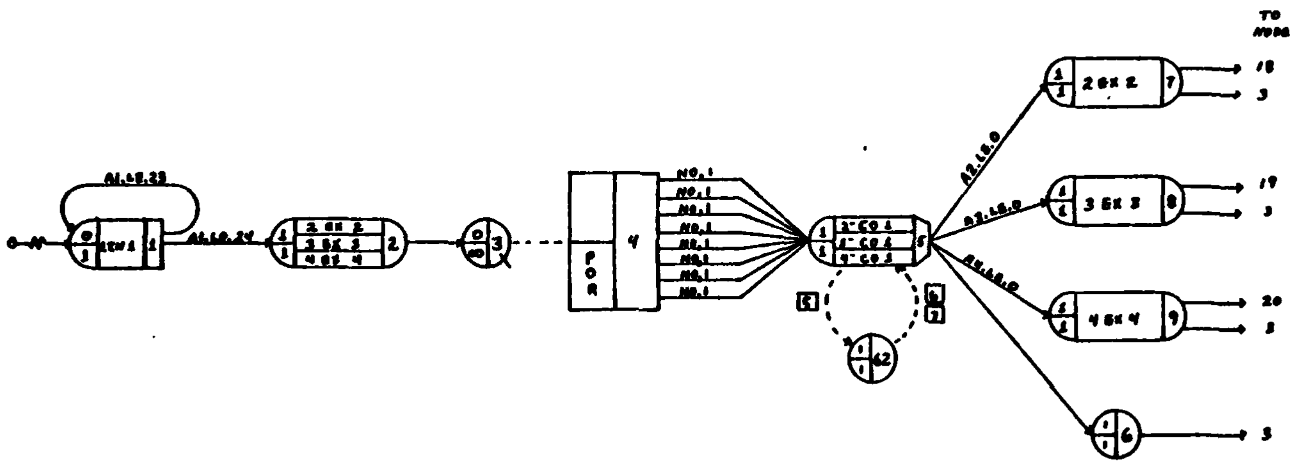


Figure 4-1. Aircraft, Sortie and System Failure Generation

As each aircraft transaction generated realizes node-2, values are assigned attributes-2,3, and 4 which indicate the number of sorties to failure of aircraft avionic systems 41B00, 74B00, and 74E00 respectively. The values assigned these attributes are draws from Exponential distributions with means corresponding to system MSBMA [27, 29].

Sortie Generation and System Failure

After the assignment of attributes for system failures, the transaction enters Q node-3, an available aircraft pool. Aircraft wait in the available pool until selected by S node-4 to fly a sortie. As shown in figure 4-1, the select node has eight activity branches emanating from it that represent sortie selection. The activities themselves do not constitute a sortie but rather establish a means by which the number of sorties flown each day can be regulated. Control of the number of sorties is realized by changing the mean of parameter set-1. Each of the eight activities emanating from S node-4 draws from the distribution defined by parameter set-1 to determine the delay time for transactions traversing the network from Q node-3 to R node-5, the sortie node. Table 4-1 lists several sortie rates that may be desired and the corresponding mean value for parameter set-1. For sortie rates not listed, the calculation performed to arrive at the proper setting of the mean of parameter set-1 is:

$$T_u = \frac{1}{\left(\frac{S_n}{S_b}\right)\left(\frac{1}{FE}\right)}$$

where, T_u is the mean of parameter set-1,
S_n is the number of sorties desired daily,
S_b is the number of branches emanating from S-node-4,
and FE is the flying envelop or number of hours of flight operations each day.

Table 4-1. Mean of parameter set-1 (T_u) required to generate S, average number of sorties per flying day

S	T_u
20	6.40
30	4.26
40	3.20
50	2.56
60	2.13
70	1.83
80	1.60
90	1.42

General Calculation of T_u

$$T_u = \frac{1}{\left(\frac{S_n}{S_b}\right)\left(\frac{1}{FE}\right)}$$

where, S_n is the number of sorties requires
S_b is the number of sortie activities
and FE is the flying envelope.

Node-5 is a regular node with conditional take-first branching and is the node that signifies completion of a sortie. When a transaction causes this node to be realized, attributes 2, 3 and 4 have one sortie decremented from the existing attribute value. If any attribute value is decremented to zero or less, the transaction traverses the appropriate branch according to the conditions of the branches and will cause realization of either R node-7, 8, or 9 to indicate a system failure. As R node-7, 8, or 9 is realized indicating system failure, the attribute for the failed system has its value reset by another draw from the system MSBMA parameter set. Branching from these reset nodes is deterministic thus two transactions are emitted upon node passage. One transaction, the aircraft, returns to the available pool while the other transaction traverses a path to a mark node with probabilistic branching that determines LRU failures.

If none of the attribute values are decremented to zero or less, the transaction is routed through R node-6 to return to the available aircraft pool.

R node-62 is part of the network that establishes control over the periods of operation and will be discussed later.

The portion of the network discussed in the previous paragraphs and illustrated by figure 4-1 can be thought of as those events exogenous to the shop operation discussed next. Figure 4-5 combines this portion with all other network sections and provides a complete representation of the system network.

LRU Failure and Repair

The portion of the system network to be discussed next refers to the network design of figure 4-2. This network section may be thought of as the avionics maintenance shop. System failures are indicated through realization of R nodes-18, 19, and 20. Each of these nodes has probabilistic branching based upon the probability of a particular LRU failure, given the system has failed. These conditional failure probabilities are based upon Air Force empirical data as described by Tetmeyer [27].

The probabilistic branches emanating from R nodes-18, 19, and 20 represent either the removal of a specific LRU from the aircraft or repair of the failed system without removal of a LRU. The branching from R node-19 illustrates a special case where historical data indicates that a representative number of failures of the system produce removal of more than one failed LRU. Each of these nodes has a path to R node-21, which is a dead end node that absorbs all transactions that result in no LRU removal. All other branching from these nodes are paths by which failed LRUs reach queues to await the availability of a test station. As mentioned in the previous section, R nodes-18, 19, and 20 also act as mark nodes that update each transaction's mark time to current simulation time thus providing a statistic by which the time spent in the shop for each LRU may be measured.

There are six Q nodes each representing the waiting time of a specific LRU type for allocation of a test station resource. Q nodes

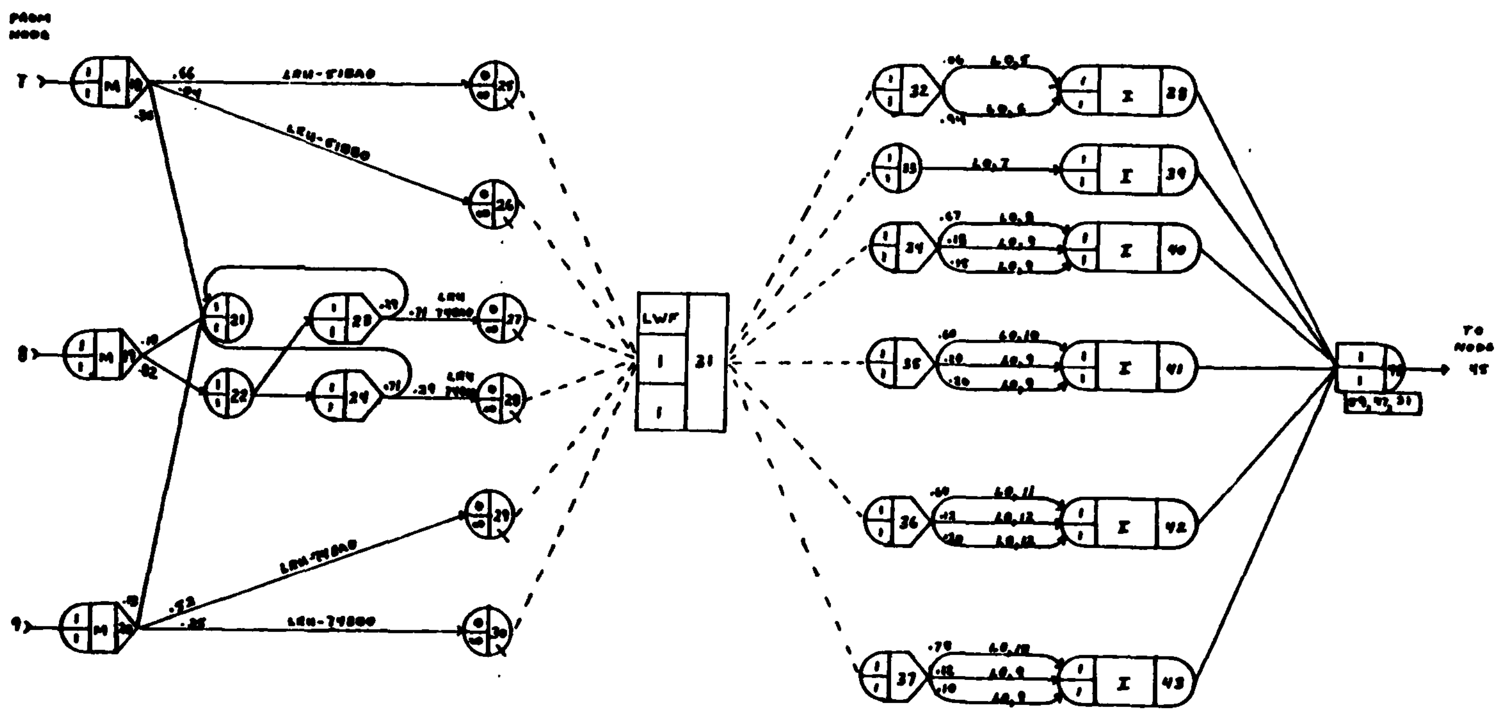


Figure 4-2. LRU Failure and Repair

25 through 30 are the LRU queues and because any LRU that fails must be repaired, there is no balking.

Allocate node, A node-31, allocates the test station resource to transactions as they arrive at the queues as long as there is a free resource. When the resource is not available, transactions must wait in the queues until the resource is freed. Queue Selection Rules of table 4-2 are used to control the method by which test stations are allocated when there is competition between queues for service. In the network of figure 4-2, the LRU that has been waiting the longest is selected for allocation, independent of queue membership.

When allocation of a test station for a particular LRU occurs, that LRU traverses a path to one of the R nodes 32 through 37 dependent upon the queue from which the transaction emanated. Each of the R nodes 32 through 37 with the exception of R node-33, has probabilistic branching that determines the type repair action to be completed. LRU repair belongs to one of three categories: bench check and repair; bench check and no repair required; and not repairable this station. Each of these repair actions for each LRU has a specific mean repair time drawn from a Lognormal distribution with the variance set at twenty-nine percent of the mean value, as described by Gunkel [15]. Upon completion of the repair activity, a statistic node is realized which collects time statistics so that the mean time in the system for each LRU type is included in the simulation output. Nodes 38 through 43 are such statistics nodes. Transactions realizing nodes 38 through

Table 4-2.* Queue Selection Rules

CODE	Key
POR	Preferred order
CYC	Cyclic
RAN	Random
LAV	Largest average number
SAV	Smallest average number
LWF	Longest waiting of first
SWF	Shortest waiting of first
LNQ	Largest number in queue
SNQ	Smallest number in queue
LNB	Largest number of balkers
SNB	Smallest number of balkers
LRC	Largest remaining capacity
SRC	Samllest remaining capacity
ASM	Assembly mode

*Extracted from Pritsker [24].

43 traverse a path to free node-44 which frees the test station resource so that it may be allocated to any waiting transaction in queue nodes 25 through 30. F node-44 also routes the transaction to R node-45.

Test Station Failure

Simulation of test failures is accomplished by R node-45 which acts as a counter. The number of transactions required to release the node is set at the mean number of LRU repair actions between test station failures as estimated by the test station vendor [4, 29]. The placement of the network section of figure 4-3 at the end of the repair cycle is a matter of networking convenience. In actuality it is more likely that a test station failure would be discovered at the beginning of a LRU repair task, but the model can not differentiate between the end of one task where the test station is released and the beginning of the next task where the test station is allocated since there is no time delay involved.

When R node 45 is realized, a transaction is released to Q Node-46 and because of the priority established for this task, transactions entering this queue will be allocated a test station ahead of any LRU waiting in queues 25 through 30. The test station failure transaction is routed from the queue through R node-48 to a repair activity. Upon completion of repair, the test station is realeased by free node-49 which allows LRU repair to begin. F node-49 routes the transaction to be absorbed by R node-21. The box at the bottom of free node-49 is the

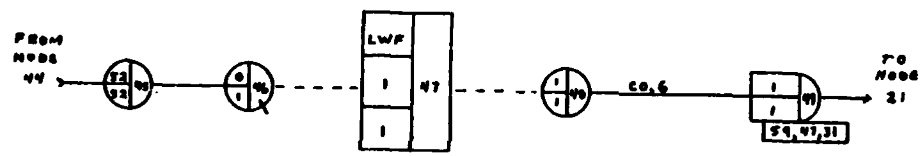


Figure 4-3. Test Station Failure and Repair

method by which test station allocation is prioritized. As indicated by the numbers 59, 47, and 31, test stations will be allocated by node 59 before node-47 etc.

Control of Time

A network device to control the number of hours of flying operations each day was previously mentioned. The network section of figure 4-4 is the network "clock" which controls periods of flying and periods of LRU repair. The source node generates a single transaction with the value of attribute-1 set to zero. When R node-57 is realized, the attribute value is increased by one and activity five begins. While activity five is in progress, node-5 of figure 4-1 is in the network and flying occurs. Upon completion of activity five, a nodal modification replaces R node-5 with node-62 which routes all transactions back to Q node-3 and all flying of sorties as indicated by realization of R node-5 stops. The transaction, upon completion of activity five, enters Q node-58 and since this allocate node has the highest priority of all allocate nodes, a test station will be allocated to this transaction as soon as it is available. In this manner, shifts are simulated with the restriction that once a job is started, it will be completed before the shift ends. R node-60 is a regular node with conditional take-first branching. The top branch is traversed if attribute-1 is less than or equal to 4. Thus, five days of operating 16 hours and not operating 8 hours will result in simulation. When attribute-1

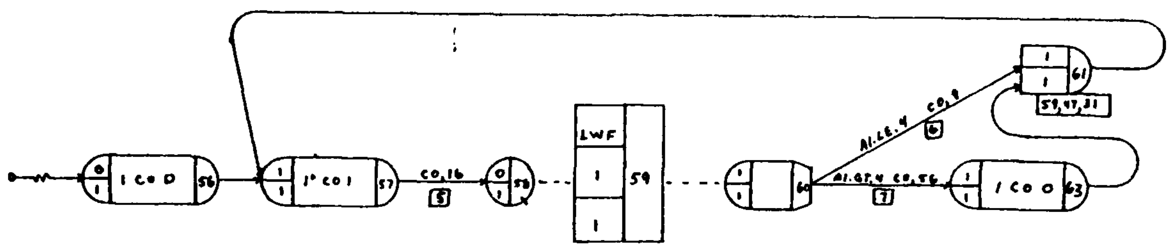


Figure 4-4. Network Clock

reaches 5, the transaction will traverse the lower branch emanating from R node-60 and operations will halt for the weekend. The two activities emanating from R node-60 are labeled activities emanating from R node-60 are labeled activities 6 and 7 and upon completion of these activities, nodal modification replaces R node-62 with R node-5 and sortie generation begins again. Completion of activity 7 also causes realization of R node 63 which resets the value of attribute 1 to zero so that upon realization of F node-63, a new week begins.

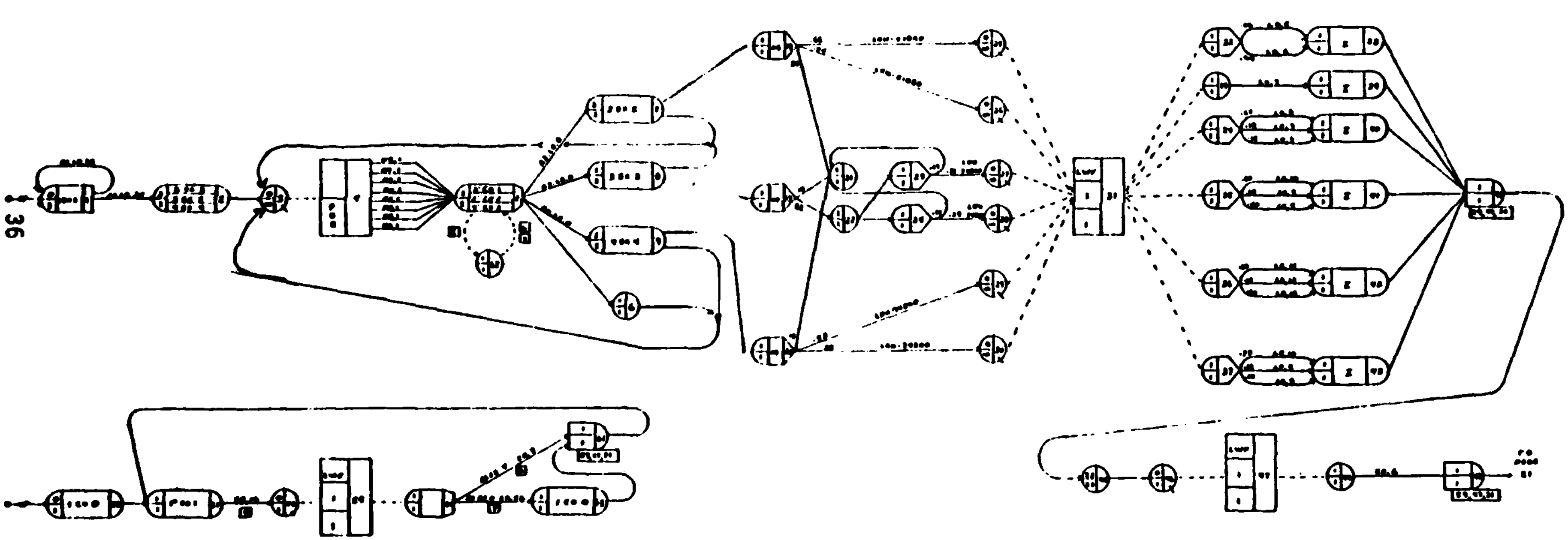


Figure 4-5. Overall System Network

V. MODEL VALIDATION

Verification of Model

Hogg states that "verification of simulation results is a complex problem" [16]. Comparison of analytic results with simulation data must allow for the statistical variation inherent in simulation. Differences will occur due to the approximation of distributions by drawing random deviates. Since these differences are known to exist, comparison only yields evidence of model verification and provides no proof of accuracy.

Within the Q-GERT model of an Air Force Avionic Intermediate Maintenance Shop system, transactions occur due to a draw from a distribution and the path each transaction follows is determined probabilistically. Finally the time each transaction is in the system is determined by resource availability and a draw from a distribution. The choice of simulation as a method to study this sytem was made due to a lack of analytic ability to model such a process.

Analytic Estimation

Analytic estimation of the output for the number of LRU failures and the mean time to repair LRU failures can be calculated. Table 5-1 shows the expected number of failures of each type LRU based upon an average 20 sorties flown each day and the prescribed system failure rate and the removal probabilities associated with each LRU. The mean number

Table 5-1 Simulated LRU Failures Compared to Expected LRU Failures

System MSBMA	LRU Name	Probability of Failure	Number Failures Expected	Mean Simulated Failures
22	51BA0	.66	13.2	13.2
	51BB0	.04	0.8	1.4
17	74BA0	.58	15.0	19.8
	74BC0	.24	6.0	8.2
13	74EA0	.52	17.6	17.2
	74EB0	.35	11.8	14.8

Number of Failures Expected, E(X) is computed:

$$\left(\frac{\text{No. Sorties}}{\text{MSBMA}}\right)\left(P(X \mid \text{system failure})\right)$$

where, X is the number of LRUs.

of failures over five simulations compare well with the expected number of LRU failures.

The expected time to repair each LRU, $E(T)$, can be estimated by:

$$E(T) = \sum_{i=1}^{n} P(X_{r_i})\ (t_{r_i})$$

where, X_{r_i} is the repair action for LRU; and t_{r_i} is the time associated with that repair.

Results of such calculations are compared to simulation results in table 5-2.

Comparison Test

It seems that by comparison, the simulation model is generating the number of failed LRUs expected and that repair of LRUs in simulation is consistent with the expected repair time. The only other parameter of the model that lends itself to this type comparison is the number of sorties flown. In this verification effort, model parameter set-1 is set to generate 20 sorties per flying day. Table 5-4 presents the sorties generated in simulation and as can be seen, the realized mean sorties generated per day is 20.

Steady State Analysis

For most analysis conducted via simulation, a steady state condition should exist. Figure 5-1 shows that test station utilization steady state is realized after six simulation runs.

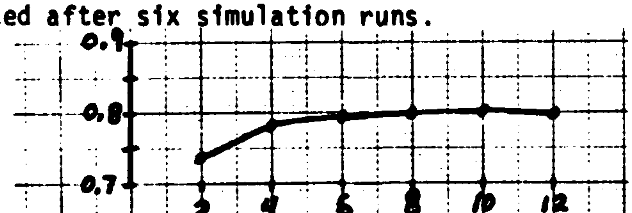


Figure 5-1. Number of Simulation Runs to Reach Steady State for Test Station Utilization

Table 5-2 Expected Repair Time Compared to Simulated Repair Time

LRU Name	Expected Time	Simulated Time
41ABO	.63	.6337
51BBO	.90	.8716
74BAO	2.61	2.5457
74BCO	2.26	2.4462
74EAO	3.12	3.0777
74EBO	2.46	2.3666

VI. COMMAND LEVEL DECISIONS

Decision Analysis with Q-GERT

Statistics are computed in simulation that describe parameters of the system such as: test station utilization; number of LRU failures; average time in the system; average number and time in the queue; and number of sorties accomplished in simulation. Q-GERT Summary Reports provide all of these statistics as output and all but the number of sorties accomplished are read directly as shown in the output example figure 6-1. The number of sorties accomplished equals the number of transaction passages of R node-5 as shown in figure 6-2.

Following is a discussion of the analysis conducted using the Q-GERT model of Chapter IV. The analysis herein illustrates the potential of Q-GERT simulation as a method to aid management in decision making. The examples used do not exhaust the list of questions managment can put to Q-GERT analysis but are representative of that list. Analysis is discussed where management must determine:

1. the number of test stations to purchase relative to the number of sorties flown each day,
2. the number of test stations to provide the maintenance organization relative to costs associated with LRU repair,
3. the number of spare LRUs to purchase to support a specified sortie rate,

GERT SIMULATION PROJECT TSDI BY LOWELL
DATE 9/ 29/ 1979

RESULTS FOR RUN 1

ELAPSED TIME FOR RUN = 168.0000

NODE STATISTICS

NODE	LABEL	AVE.	NO OF OBS.	TYPE OF STATISTICS
43		29.5590	8.	I
42		25.2646	13.	I
41		NO VALUES RECORDED		
40		21.2376	5.	I
39		19.7923	3.	I
38		27.8914	3.	I

NUMBER IN Q-NODE ** WAITING TIME ** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
3	ACFT	15.9966	0.	16.	16	4.9220
25	FARAC	1.6537	0.	3.	3	46.3044
26	FARBO	.3336	0.	2.	0	18.6812
27	GDRAO	1.7961	0.	4.	3	37.7184
28	GDRCO	.0000	0.	0.	0	.0000
29	GDFAC	4.0480	0.	6.	5	37.7810
30	GDEBO	2.9215	0.	6.	4	40.9010
58		.0357	0.	1.	0	1.1995
46		.0000	0.	0.	0	.0000

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
100		1	1.0000	.0000	168.0000
99		1	1.0000	.0000	168.0000
98		1	1.0000	.0000	168.0000
97		1	1.0000	.0000	168.0000
96		1	1.0000	.0000	168.0000
95		1	1.0000	.0000	168.0000
94		1	1.0000	.0000	168.0000
93		1	1.0000	.0000	168.0000

NO. BALKING PER UNIT TIME

NODE	LABEL	AVE.
3	ACFT	.0000
58		.0000
46		.0000

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	TSDI	1	.950	1	0	.050	1

Figure 6-1. Q-GERT Summary

NODE	TRANSACTION PASSAGES
3	1351
4	1351
5	658
6	528
7	33
8	40
9	57
18	33
19	40
20	57
21	64
22	34
23	34
24	34
25	21
26	3
27	22
28	7
29	32
30	16
31	101
32	21
33	3
34	22
35	7
36	32
37	16
38	21
39	3
40	22
41	7
42	32
43	16
44	101
45	1
46	1
47	1
48	1
49	1
57	23
60	22
62	693
63	4

Figure 6-2. Node-5 indicates number of Sorties Flown

4. the time period required to complete repair of an existing backlog of failed LRUs,
5. test station availability for training when a proposed flying schedule is given,
6. if the number of failures realized for a given LRU during some period is representative of the aircraft system estimated mean failure rate,
7. the dimensions of the storage space required for failed LRUs awaiting maintenance relative to the number of sorties flown per day.

Questions of the type illustrated by the first three examples represent command level decisions, and are discussed in this chapter. The remaining questions are more of the day to day decision requirements of local management and will be the topic of Chapter VII. Discussion of the analysis involved in these decisions is intended to substantiate the proposal that Q-GERT is a viable tool to be used by Air Force management during both the acquisition and operational cycle of a weapon systems life.

Test Station Acquisition Relative to Sortie Requirements

Problems Encountered in Test Station Acquisition

Determination of the number of test stations to purchase must be made early in the acquisition program. Generally, the only information available at the time a decision is made consists of estimates of:

system mean time to failure; probability of component black-box failures given the system failure; probability of the type repair action required; and the mean time to repair for each type repair action. One other test station utilization parameter that is known is the number of sorties per day that will be required for each flying unit. With this information at hand, Air Force managers must determine how many test stations will be required at each installation responsible for repair of the specified aircraft systems and the LRUs associated with those systems. The number of test stations purchased can be based on the flying units' deployment responsibility. Decisions made in this manner will authorize the unit that must support two combat operating locations two test stations while the unit that remains intact during combat deployment will be authorized only one test station.

Authorization based upon this deployment factor has merit in that it is obvious that to support two separate and independent operations, a minimum of two test stations is definitely required. The problem that exists in this method of authorization is that there is no attempt to determine the sufficiency or support effectiveness of the single test station.

Development of Decision Criteria

Intelligent decision making concerning the acquisition of test stations must include the determination of test station utilization

based upon mission requirement. In that the number of sorties flown per day is the measure of a flying unit's mission requirement, the decision maker must in some way relate this sortie requirement to test station utilization.

Simulation of the Q-GERT model design of Chapter IV will provide this much needed estimate of the relationship between the number of sorties flown and test station utilization. Output statistics of several simulation runs over a range of sortie rates can be analyzed using linear regression to estimate test station utilization, dependent on the average number of sorties flown daily. Such a method requires that at least five simulation runs at each sortie rate be conducted and that the sorties rates used in simulation exceed the maximum potential sorties requirement. Requirement of five simulation runs of each sortie rate is based upon the common practice of using 4 or 5 samples in a subgroup to estimate mean statistics [14]. Simulating at a higher sortie rate than the estimated extreme will insure that the regression line includes the possible sortie rates of interest. The regression line determined using output statistics of these simulations may be used to compute the test station utilization factor for any sortie rate in the range of regression. Confidence intervals about the mean points of regression are established to provide the manager with a clearer understanding of the statistic he will use in a decision.

Regression provides data for graphical representation of test station utilization versus the number of sorties flown per day. This

graphical representation is easily read and understood by management. Management can, with the confidence level described on the graph, determine the expected test station utilization factor for any desired sortie rate [6]. This method of decision making will allow management more knowledge of the system and more confidence in the conclusions made.

Simulation and Regression Analysis

As an example of the above described procedure, simulation was conducted to generate output statistics of test station utilization for eight sortie rates. The sortie rates ranged from 20 sorties per day to 90 sorties per day in intervals of 10 sorties per day. Simulation at each sortie rate was replicated five times with the average test station utilization statistic for each simulation used to compute an overall average test station utilization statistic, Y. An illustration of the simulation output used to determine Y is presented as figure 6-3. Output statistics of Y for each set of simulation runs were used in conjunction with the appropriate corresponding sortie rate, X. Table 6-1, presents the simulation output and computations performed to arrive at the expression:

$$Y_C = .0045 + .0116X$$

where, X is the number of sorties per day

and Y_C is the resultant mean test station utilization;

which gives management the ability to calculate an expected test station utilization factor for any sortie rate desired.

AVERAGE RESOURCE UTILIZATION / **NUMBER OF RESOURCES**

RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	MAX.
1	TS01	.6192	.0260	.0116	5.	.5771	.6407	3.

AVERAGE RESOURCE AVAILABILITY / **NUMBER OF RESOURCES**

RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	MAX.
1	TS01	2.3808	.0260	.0116	5.	2.3593	2.4229	3.

Figure 6-3. Test Station Utilization Output Summary

Table 6-1. Computation for Regression of Simulated Number of Sorties Flown Daily on Test Station Utilization

Number of Sorties Flown Per Day X	Test Station Utilization Y	XY	X^2	Y^2
20	.24	4.8	400	.0576
30	.33	9.9	900	.1089
40	.46	18.4	1600	.2116
50	.62	31.0	2500	.3844
60	.69	41.4	3600	.4761
70	.83	58.1	4900	.6889
80	.93	74.4	6400	.8649
90	1.04	93.6	8100	1.0816
440	5.14	331.6	28400	3.8740

$n = 8$ $\quad \Sigma X_i Y_i = 331.6$

$\Sigma X_i = 440$ $\quad \bar{X} = 55$ $\quad \Sigma X_i^2 = 28400$

$\Sigma Y_i = 5.14$ $\quad \bar{Y} = .6425$ $\quad \Sigma Y_i^2 = 3.874$

$$b = \frac{\frac{\Sigma X_i Y_i}{n} - \bar{X}\bar{Y}}{\frac{\Sigma X_i^2}{n} - (\bar{X})^2} = .0116 \quad \text{and} \quad a = \bar{Y} - b\bar{X} = .0045$$

which yields: $Y_c = .0045 + .0116(X)$

Calculation of Y_c for sortie rates over the range of the regression line enables computation of the conditional standard deviation of the estimate of test station utilization. Comparison of simulation resultant Y with computation for Y_c to determine an estimated standard deviation S_{Y_c} is shown in table 6-2. This standard deviate is used to construct 95 percent confidence intervals about the estimated mean test station utilization, Y_a as shown in table 6-3.

Values of Y_c and Y_a are used to construct the graph of figure 6-4 which provides management with a means to select the mean test station utilization expected for a given sortie rate. They will be able to use this graph with 95 percent confidence that the actual test station utilization will be in the interval indicated by the dotted lines.

Decision Rule

Test station acquisition decisions can be made with the aid of the information provided in figure 6-4. Management has only to determine the sortie rate which must be supported and then by selecting the point along the X-axis that represents the desired sortie rate, a point on the regression line can be identified. From the point on the regression line that corresponds to the sortie rate of interest, they can trace across to the Y-axis and read the expected test station utilization.

Table 6-2. Computation of the Estimate of Test Station Utilization Conditional Standard Deviation

Number of Sorties Flown Per Day X	Test Station Utilization Y	Conditional Test Station Utilization Y_c	Deviation $Y - Y_c$	Square of Deviation $(Y - Y_c)^2$
20	.24	.2365	.0035	.000012
30	.33	.3525	-.0225	.000506
40	.46	.4685	-.0085	.000072
50	.62	.5845	.0355	.001260
60	.69	.7005	-.0105	.000110
70	.83	.8165	.0135	.000182
80	.93	.9325	-.0025	.000006
90	1.04	1.0485	-.0085	.000072
440	5.14	5.1400	0	.002220

$$S_{Y/X} = \sqrt{\frac{\Sigma(Y_i - Y_c)^2}{n - 2}} = .0192 \quad \text{and} \quad S_{Y_c} = \frac{\hat{S}_{Y/X}}{\sqrt{n}} = .0068$$

Table 6-3. Computation of 95 Percent Confidence Intervals for Y_a

No. of Sorties X	$(X - \overline{X})$	$(X - \overline{X})^2$	S_{Y_a}	Y_c*	Y_a**
20	-35	1225	.0219	.2365	.2365 $\pm$ .0473
25	-30	900	.0215	.2945	.2945 $\pm$ .0464
30	-25	625	.0212	.3250	.3250 $\pm$ .0458
35	-20	400	.0209	.4105	.4105 $\pm$ .0451
40	-15	225	.0207	.4685	.4685 $\pm$ .0447
45	-10	100	.0205	.5265	.5265 $\pm$ .0443
50	-05	25	.0204	.5845	.5845 $\pm$ .0441
55	0	0	.0204	.6425	.6425 $\pm$ .0441
60	05	25	.0204	.7005	.7005 $\pm$ .0443
65	10	100	.0205	.7585	.7585 $\pm$ .0447
70	15	225	.0207	.8165	.8165 $\pm$ .0451
75	20	400	.0209	.8745	.8745 $\pm$ .0458
80	25	625	.0212	.9325	.9325 $\pm$ .0458
85	30	900	.0215	.9905	.9905 $\pm$ .0464
90	35	1225	.0219	1.0485	1.0485 $\pm$ .0473
		7000			

* $S_{Y_a} = S_{Y/X} \sqrt{1 + \frac{1}{n} + \frac{(X - \overline{X})^2}{\sum (X - \overline{X})^2}}$ and ** $Y_a = Y_c \pm t_{(13,.025)} \frac{S_{Y_a}}{\sqrt{n}}$

where, $S_{Y/X}$ is .0192

where, $t_{(13,.025)}$ is 2.16

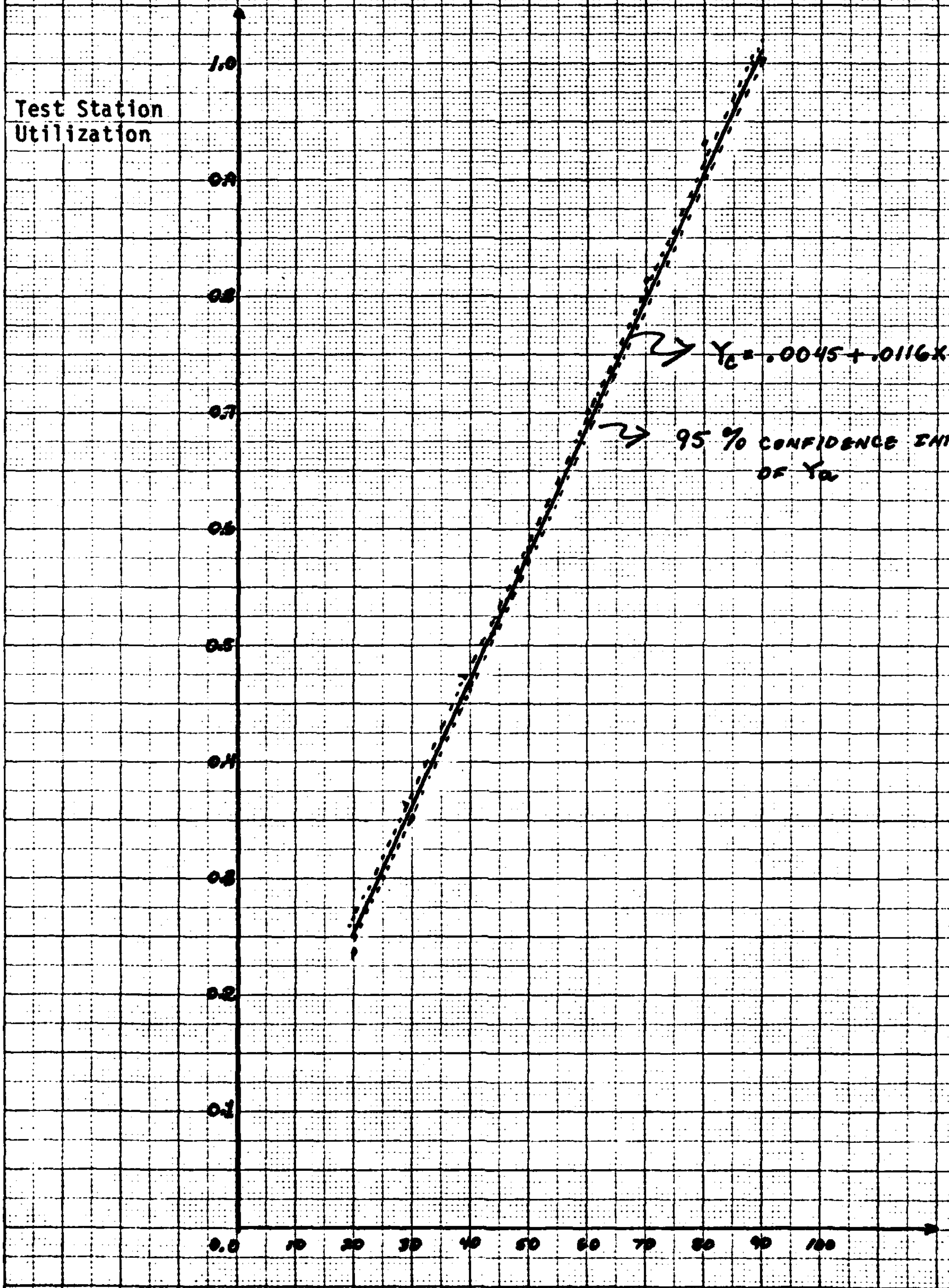


Figure 6-4. Regression of Number of Sorties on Test Station Utilization with 95% Confidence Intervals

Test Station Acquisition Relative to LRU Repair Costs

Assumption of Repair Criticality

Assume that the number of sorties required per day is not the primary measure by which test station support requirements are established. During the period of initial weapon system build-up it is possible that spares levels will not be at the estimated requirement. Due to the complexity of manufacturing, the contractor may not be able to provide production and spare level demands for some critical LRUs. Such a situation may make the repair cycle time of a LRU more important since this repair time represents a time constraint on the generation of sorties. If spares for a particular LRU are not available, and that LRU is a critical flight item, the aircraft must wait until the LRU is repaired before it can fly.

Under such circumstances, management would like to know more about the time to repair the LRU in question. The repair time with one test station available could be compared to the repair time when two test stations are in use to measure the effect of having an additional test station available.

Repair Time Probability Distribution

Analysis that will provide probability distributions of repair cycle times for LRUs can be accomplished using Q-GERT. Statistic node histograms can be requested for the statistic nodes associated with the LRUs of interest. Each histogram will provide a graphical representation of the mean repair cycle time for the simulation runs with

a table listing the relative frequency and the cumulative frequency of those mean repair cycle times. The cumulative frequency describes the probability distribution of repair cycle time that may be used in the decision process.

Simulation of Alternatives

Twelve simulation runs were conducted with both one and two test stations in use. Analysis of the output from these simulations is conducted for LRU 51BAO as an illustrative example of the method. Histogram output from simulation is shown as figures 6-5 and 6-6. The first figure displays simulation results of one test station and the second figure displays the simulation of two test stations in use. The statistics listed under column heading CUML FREQ in these figures can be interpreted as the probability that the repair cycle time is equal to or less than the corresponding time in the column heading UPPER BOUND OF CELL. As can be seen in figure 6-5, with one test station, the probability of the repair cycle being six hours or less is .083, while the maximum repair cycle time of figure 6-6 is 1.8 hours. If management can determine the time period that is acceptable for repair, they can use these statistics to make the decision between one or two test stations.

Determination of Decision Rule

Let's assume that the situation described in the preceding paragraphs will exist for about one year. That is, in one year, spare LRUs

I STAT HISTOGRAM FOR NODE 38

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER BOUND OF CELL
0	.000	.000	.00
0	.000	.000	2.00
0	.000	.000	4.00
1	.083	.083	6.00
3	.250	.333	8.00
1	.083	.417	10.00
1	.083	.500	12.00
1	.083	.583	14.00
2	.167	.750	16.00
2	.167	.917	18.00
0	.000	.917	20.00
0	.000	.917	22.00
0	.000	.917	24.00
0	.000	.917	26.00
1	.083	1.000	28.00
0	.000	1.000	30.00
0	.000	1.000	32.00
0	.000	1.000	34.00
0	.000	1.000	36.00
0	.000	1.000	+INF
TOTAL 12			

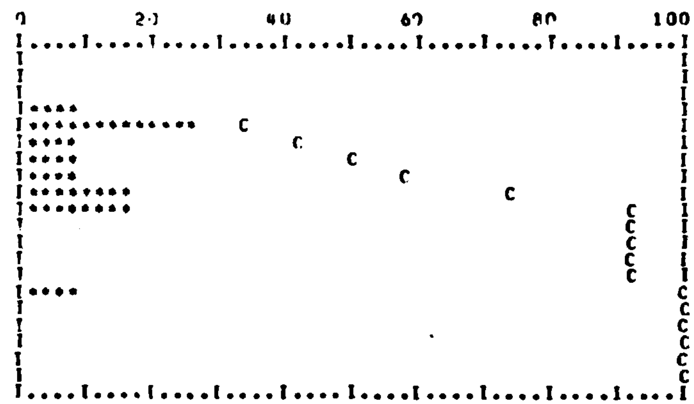


Figure 6-5. Histogram of Repair Cycle Time for LRU 51BA0 with One Test Station in Use

T STAT HISTOGRAM FOR NODE 38

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER BOUND OF CELL
0	.000	.000	.00
0	.000	.000	.20
0	.000	.000	.40
4	.333	.333	.60
0	.000	.333	.80
4	.333	.667	1.00
3	.250	.917	1.20
0	.000	.917	1.40
1	.083	1.000	1.60
0	.000	1.000	1.80
0	.000	1.000	2.00
0	.000	1.000	2.20
0	.000	1.000	2.40
0	.000	1.000	2.60
0	.000	1.000	2.80
0	.000	1.000	3.00
0	.000	1.000	3.20
0	.000	1.000	3.40
0	.000	1.000	3.60
0	.000	1.000	+INF
TOTAL 12			

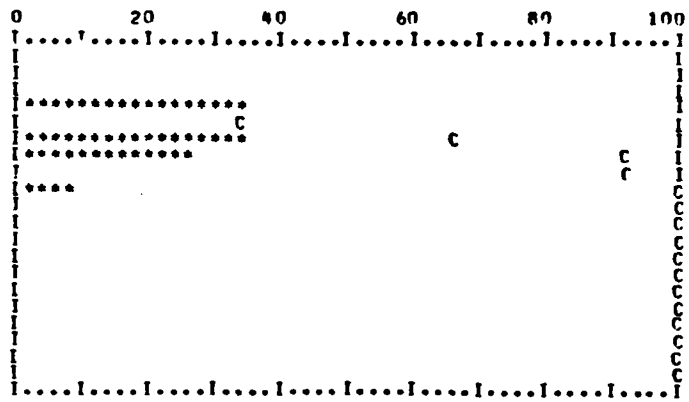


Figure 6-6. Histogram of Repair Cycle Time for LRU 51 BAO with Two Test Stations in Use.

will become available. The cost of an additional test station for one year is estimated by management at \$100,000.00 and repair cycle time is valued at \$50.00 per hour. With these cost estimates, the histogram output of figures 6-5 and 6-6, plus the expected number of LRU failures per week at the sortie rate simulated as indicated in figures 6-7 and 6-8, a decision rule may be determined.

The expected number of failures is 5 per week which is 260 per year. The expected cost of these failures is computed as:

$$E(c) = 260tP(t)C$$

where, t repair time
$P(t)$ probability of the repair time
and C cost of repair.

Tables 6-4 and 6-5 present the results of these calculations which show that it is less expensive to expend the \$100,000.00 for an additional test station for a year than to operate with just one test station.

Spare LRU Acquisition

LRU Constraints on Sorties

Test station acquisition is only one of several decisions involved in the total avionic maintenance support area. In the first section of this chapter, test station utilization was considered independent of the number of spare LRUs available. This assumption is valid in that test station utilization is independent of whether the LRU is constraining the aircraft. The fact is that such a constraint will effect sortie generation and must be a consideration by management. If a given LRU

GERT SIMULATION PROJECT TSDT BY LOWELL

DATE 9/ 29/ 1979

FINAL RESULTS FOR FIRST SIMULATION

TOTAL ELAPSED TIME = 168.0000

NODE STATISTICS

NODE	LABEL	AVE.	STD.DEV.	NO OF OBS.	STAT TYPE
43		14.6212	9.8222	9.	I
42		11.7619	10.1703	10.	I
41		17.8277	12.2990	2.	I
40		9.8664	9.4374	5.	I
39		1.2285	.0000	1.	I
38		1[illegible].7524	10.3623	5.	I

NUMBER IN QUEUE / ** WAITING TIME ** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
3	RRFT	15.9970	0.	16.	16	6.1219
25	FARAO	.9633	0.	2.	2	23.1272
26	FARBO	.0000	0.	0.	0	.0000
27	FBBAO	.5935	0.	3.	[illegible]	16.6736
28	FBBCO	.4621	0.	1.	[illegible]	25.0763
29	FBEAO	1.8324	0.	4.	3	19.6037
30	FBEBO	1.4559	0.	5.	[illegible]	23.2278
58		.2634	0.	1.	0	2.1315
46		.0000	0.	0.	0	.0000

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
100		1	1.0000	.0000	168.0000
99		1	1.0000	.0000	168.0000
98		1	1.0000	.0000	168.0000
97		1	1.0000	.0000	168.0000
96		1	1.0000	.0000	168.0000
95		1	1.0000	.0000	168.0000

Figure 6-7. Average Number of Failures of LRU 51BAO

GERT SIMULATION PROJECT TSDT   BY LOWELL
DATE 9/ 29/ 1979

FINAL RESULTS FOR FIRST SIMULATION

TOTAL ELAPSED TIME = 168.0000

NODE STATISTICS

NODE	LABEL	AVE.	STD.DEV.	NO. OF OBS.	STAT TYPE
43		3.6411	2.0115	8.	I
42		3.3351	1.0725	15.	I
41		4.6190	.0000	1.	I
40		2.0047	.8818	4.	I
39		1.2285	.0000	1.	I
33		.9994	1.1169	5.	I

NUMBER IN Q-NODE   ** WAITING TIME ** IN QUEUE

NODE	LABEL	AVE.	MIN.	MAX.	CURRENT NUMBER	AVERAGE
3	ACFT	15.9976	0.	16.	16	6.1501
25	5ABA0	.0157	0.	1.	0	.5292
26	5ABB0	.0000	0.	0.	0	.0000
27	60BA0	.0000	0.	0.	0	.0000
28	60BC0	.0089	0.	1.	0	1.4979
29	60EA0	.0201	0.	1.	0	.2246
30	60EB0	.0382	0.	1.	0	.8027
59		.0006	0.	1.	0	.0216
46		.0000	0.	0.	0	.0000

SERVER UTILIZATION

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
100		1	1.0000	.0000	168.0000
99		1	1.0000	.0000	168.0000
98		1	1.0000	.0000	168.0000
97		1	1.0000	.0000	168.0000
96		1	1.0000	.0000	168.0000
95		1	1.0000	.0000	168.0000

Figure 6-8. Average Number of Failures of LRU 51BA0

Table 6-4. Expected Cost of Operation with One Test Station

Repair time t	Cost C	Probability of t P(t)	Expected cost
6	$ 78000	.083	$ 1079.00
8	104000	.250	26000.00
10	130000	.083	10790.00
12	156000	.083	12948.00
14	182000	.083	15106.00
16	208000	.167	34736.00
18	234000	.167	39078.00
28	364000	.083	30212.00
			$169949.00

Table 6-5. Expected Cost of Operation with Two Test Stations

Repair time t	Cost C	Probability of t P(t)	Expected cost
0.6	$ 7800	.333	$ 2597.40
1.0	13000	.333	4329.00
1.2	15600	.250	2900.00
1.6	20800	.083	1726.40
			$12552.80

Cost of Additional Test Station	$100,000.00
Plus Cost of Maintenance	12,552.80
Total Cost of Operation	$112.552.80

is aircraft constraining, Air Force managers would like to establish spares levels such that no flight is ever lost due to the lack of a spare LRU. Although this is generally not economically feasible, there is a definite need to know what level of spare LRUs would provide such support.

The spare LRU requirement issue, like the test station decision, must be resolved long before empirical data is available. This situation lends itself to simulation with the use of estimates of failure and repair parameters just like the test station utilization question. The model of chapter IV must be modified to provide output statistics describing the demand distribution for a given LRU. Once again the LRU 51BA0 will be used to illustrate network modification and the eventual decision analysis.

Required Model Modification

The modification required involves the addition of four nodes and a resource for each LRU to be analyzed. Since this example involves only LRU 51BA0, the modification of the network branch between R node-18 and Q node-25, and the branch between statistic node-38 and F node-44 is required. As shown in figure 6-9a, the insertion of Q node-70 and allocate node-71 make the availability of a spare LRU necessary before the failed LRU may be processed for repair. Regular node-72 is necessary since in Q-GERT, a Q node can not follow an allocate node. Free node-73 is inserted between statistic node-38 and free node-44 as shown in figure 6-9b, to free the LRU after repair is completed.

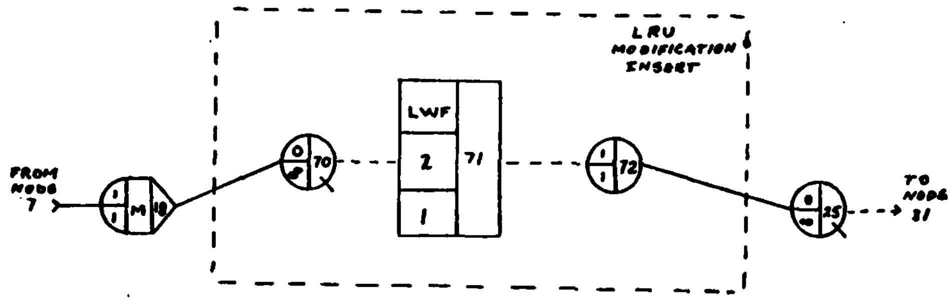


Figure 6-9a. Network Modification to Allocate Spare LRUs

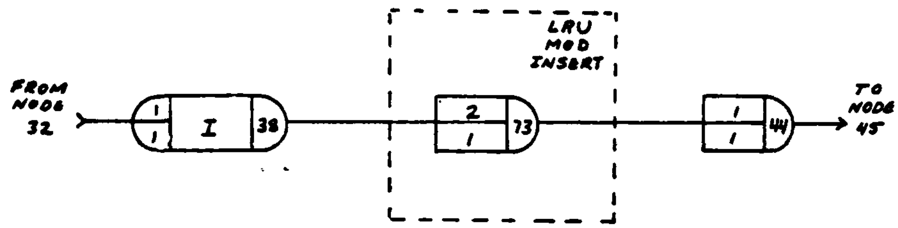


Figure 6-9b. Network Modification to Free LRU

Simulation to Determine Demand Probability Distribution

With these modifications and the establishment of the LRU resource level high enough to meet any demand, simulation is used to determine the demand distribution. Knowledge of the distribution for the probability of demand will aid management in the decision concerning the number of spare LRUs to purchase.

As in previous simulation analysis, management must have enough knowledge of the system to determine the number of sorties required and the work shift structure to be used. Herein it is assumed that 40 sorties per day is the flight requirement and the work week consists of two 8-hr. shifts, operating five days per week. The LRU spare resource level is set at five, which seems reasonable based on previous simulation results.

Sixty 1-day simulation runs were conducted and the demand for LRU 51BA0 was used to construct table 6-6. These simulation observations were grouped according to the number of demands and probability distribution p(D) and cumulative probability P(D) estimates were computed as shown in table 6-7.

Application of Inventory Decision Model

Since spare LRU stock has the same properties of inventory, a discrete inventory decision model is used to help structure a decision rule for spare LRU purchases. First it is assumed that a cost can be determined that would represent the loss of a sortie due to demand

Table 6-6. Simulation Observations of LRU 51BA0 Demands for Sixty Runs

Run #	D	Run #	D	Run #	D	Run #	D
1	1	16	0	31	0	46	0
2	1	17	1	32	0	47	2
3	1	18	1	33	1	48	0
4	1	19	2	34	0	49	1
5	0	20	1	35	1	50	1
6	1	21	1	36	0	51	1
7	1	22	1	37	1	52	0
8	3	23	1	38	1	53	0
9	2	24	0	39	0	54	0
10	0	25	1	40	1	55	1
11	1	26	1	41	0	56	0
12	0	27	1	42	1	57	1
13	1	28	1	43	0	48	0
14	1	29	0	44	3	59	2
15	2	30	0	45	1	60	0

Table 6-7. Probability Distribution for Demands of 51BA0

No. Demands	No. Observations	p(D)	P(D)
0	22	.367	.367
1	31	.517	.884
2	5	.083	.967
3	2	.033	1.000

exceeding spares stock by one. Let us assume that this cost C_2 is found to be \$500.00. The cost of having one excess spare LRU C_1 is equal to the LRU purchase price of \$100.00. Morris (21), describes a procedure where first forward difference and first backward difference inequations are used to derive the inequality:

$$P(I_0 - 1) \leq \frac{C_2}{C_1 + C_2} \leq P(I_0)$$

where, I_0 is the optimum inventory level.

Using the above inequality and the cumulative probability distribution of table 6-7, the following results were obtained:

$$\frac{C_2}{C_1 + C_2} = .83$$

inspection reveals that the critical ratio .83 falls between P(0)=.367 and P(1)=.884 thus

$$P(I_0 - 1=0) = .367 \leq .83 \leq P(I_0 = 1) = .884$$

and the best choice is to buy one spare LRU 51 BAO. Such a decision will minimize total expected costs of sparing this LRU.

Alternative Decision Models

This analysis provides optimization when cost is known of can be estimated. When such costs are impossible to obtain, other methods of decision analysis may be employed. One of these is the principle of most probably future. The probabiltiy distribution, p(D) of table 6-7 shows the probability of one demand to be greater than the probability

of any other single quantity. The most probably future method of decision making will result in the same decision as the previous method.

Another principle of choice that could be used is that of aspiration level. Use of this method requires the decision maker to determine an acceptable level of loss. Put another way, he must decide what chance he is willing to accept that a sortie will be lost due to the demand exceeding spares levels, before the decision rule can be formulated. Expressed in mathematical form this is:

$$P(L|I_0 = D) = 1-P(D)$$

If management is willing to accept a 10 percent chance of losing a sortie, the decision will be to set the spare LRU level at two since:

$$P(L|I_0 = 1) = 1-.884 = .116$$

and

$$P(L|I_0 = 2) = 1-.967 = .033$$

so

$$.003 \leq .10 \leq .116$$

VII. BASE LEVEL DECISIONS

Base level managers are allocated resources at levels determined by Command level decision makers. Utilization of the given resources, in a manner to adequately support the mission, is the responsibility of these base level managers. This chapter illustrates the use of Q-GERT analysis as an aid to management at this level. Each problem discussed is purely hypothetical; used only to illustrate the type question resolved daily by base level management.

Backlog of Failed LRUs

Purpose of Analysis

Suppose the shop supervisor has an unusually high backlog of failed LRUs and he wishes to request a period of no flying while he clears this backlog. He must know, with some degree of confidence, how long it will take to return all failed units to serviceable status.

Required Model Modification

Prior to simulation, the Q-GERT model must be modified to describe the system starting with existing queues. The modification requires the removal of all nodes in the network preceeding the six LRU Q nodes. Deleting this part of the network eliminates sortie generation and the failures caused by sorties. A source node replaces the removed network section as shown in figure 7-1a. The configuration of this source node

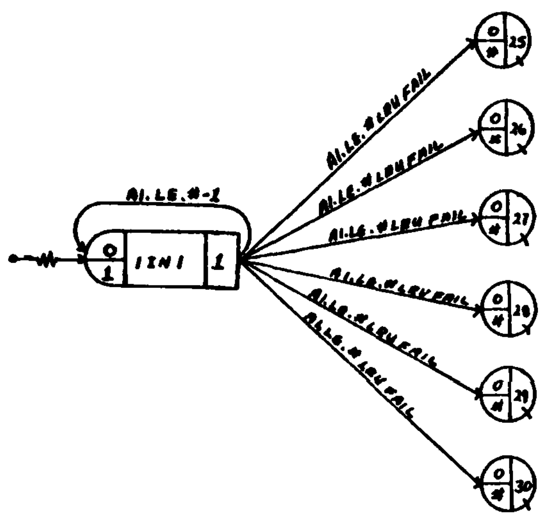


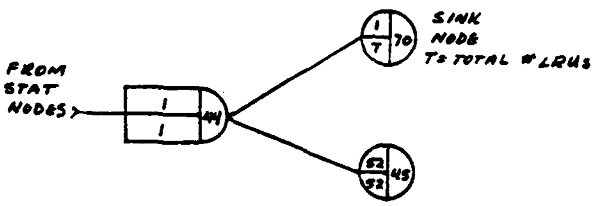
Figure 7-1a. Network Modification to Control Initial Queue Quantities

is such that it generates the desired number of failed LRUs. The source node has conditional take-all branching with a branch leading to each of the LRU queues. Another branch emanating from the source cycles back to cause successive realizations of the node. The source node also serves as an increment node and incrementally increases the value of attribute-1 by one on each realization of the node. Each branch leading to a Q node has the condition A1.LE.#, where # is the number of failed LRUs desired in the queue at the beginning of each simulation run. The branch returning to the source node will have the condition A1.LE.#-1, where # is the greatest number of LRUs desired in any of the queues. This will stop the source node from creating transactions once all the queues reach the desired number of failed LRUs.

Since there is no requirement to control shifts or days of operation, nodes 56 through 63 are deleted, and a sink node is inserted after free node-44 in parallel with the test station failure portion of the network. This last modification is shown in figure 7-1b. Simulation input for this modified network is presented as figure 7-2.

Determination of Mean Repair Time

The model now represents a shop with established non-increasing queues. At the onset of simulation, repair of LRUs will begin and will continue until all queues are empty and the last LRU is repaired. At such time the simulation will stop since no activities will be in process.



Fibure 7-1b. Network Modification to End Simulation
Based on Initial Number in Queues

```
LOW=72UE(1).TSDI
@RUN,/R LOWQUE,96J9P7FT,PIEE223R,560
@SYM PRINT$,,PSEB
@PRT,F LOW=72UE.TSDI
@XQT DS=PERT.C
GEN,LOWELL,TSDI,,,29,1979,5,1,100,168,10,E,,1=
PAR,5,1.1,.5,1.5,.32=
PAR,6,.6,.3,1.0,.17=
PAR,7,.5,.4,1.5,.26=
PAR,8,3.1,1.5,4.5,.9=
PAR,10,2.7,1.4,4.1,.79=
PAR,9,1.6,.9,2.9,.46=
PAR,11,3.6,1.6,5.4,1.0=
PAR,12,2.1,1.0,3.1,.61=
SOU,1,0,1,A=
VAS,1,1,IN,1=
REG,21,1,1=
QUE,25/FARAO,0,10,(10)31=
QUE,26/FARBO,0,10,(10)31=
QUE,27/GDRAO,0,10,(10)31=
QUE,28/GDRCO,0,10,(10)31=
QUE,29/GDEAO,0,10,(10)31=
QUE,30/GDEBO,0,10,(10)31=
ACT,1,1,,,,,,A1.LE.9=
ACT,1,25=
ACT,1,26=
ACT,1,27=
ACT,1,28=
ACT,1,29=
ACT,1,30=
RES,1/TSDI,1,47,31=
ALL,31,POR,1,1,25/32,26/33,27/34,28/35,29/36,30/37=
REG,32,1,1,P=
REG,33,1,1=
REG,34,1,1,P=
REG,35,1,1,P=
REG,36,1,1,P=
REG,37,1,1,P=
STA,38,1,1,,I=
STA,39,1,1,,I=
STA,40,1,1,,I=
STA,41,1,1,,I=
STA,42,1,1,,I=
STA,43,1,1,,I=
FRE,44,,1,1,47,31=
STR,2,1,1=
REG,45,52,52=
QUE,46,0,1,(10)47=
ALL,47,LNC,1,1,46/48=
REG,48,1,1=
FRE,49,,1,1,47,31=
ACT,32,38,LO,5,,,,.06=
ACT,32,38,LO,6,,,,.94=
ACT,33,39,LO,7=
ACT,34,40,LO,8,,,,.67=
ACT,34,40,LO,9,,,,.18=
ACT,34,40,LO,9,,,,.15=
ACT,35,41,LO,10,,,,.6=
ACT,35,41,LO,9,,,,.2=
ACT,35,41,LO,9,,,,.2=
ACT,36,42,LO,11,,,,.66=
ACT,36,42,LO,12,,,,.12=
ACT,36,42,LO,12,,,,.2=
ACT,37,43,LO,10,,,,.78=
ACT,37,43,LO,9,,,,.12=
ACT,37,43,LO,9,,,,.1=
ACT,38,44=
ACT,39,44=
ACT,40,44=
ACT,41,44=
ACT,42,44=
ACT,43,44=
ACT,44,45=
ACT,44,2=
ACT,45,46=
ACT,45,49,CO,6.=
ACT,49,21=
FIN=
@FIN

@XQT DS=PERT.C
```


Figure 7-2. Input Cards for Analysis of Backlogs

Table 7-1. Computation of Mean Time to Clear all Queues

Elapsed Time for Run (T)	$T - \bar{T}$	$(T - \bar{T})^2$
121.61	-5.108	26.012
125.00	-1.718	2.952
129.05	2.332	5.438
125.80	-0.918	0.843
122.34	-4.378	19.167
134.99	8.272	68.426
128.46	1.742	3.035
126.82	0.102	0.010
121.31	-5.408	29.246
131.80	5.082	25.827
1267.18	0	180.956

$n = 10$ $\bar{T} = 126.718$

$s^2 = 20.106$ $s = 4.484$

$t_{(10,.025)} = 2.228$

$$T_a = \bar{T} \pm t\,(\nu, \alpha/2)\; s/\sqrt{n} = 126.718 \pm 3.159$$

Simulation output summary statistic ELAPSED TIME FOR RUN illustrated by figure 7-3 can be used to compute a mean time to clear all queues. Statistical inference tests with the Student-t distribution is then used to establish confidence intervals about the mean time to clear all queues.

An Example Simulation and Results

For the purpose of analysis, simulation was conducted with ten failures in each ququе upon activitation of the model. Ten simulation runs were completed and the time statistic from each was used as shown in table 7-1 to compute a mean time to clear all queues. Ninety percent confidence intervals about the mean were computed with the results showing the expected time to clear the queues being between 5.1 and 5.4 days. With this information, the superivsor could, with 95 percent confidence, support a request for a six day stand-down.

Planning Training

Purpose of Analysis

Suppose the shop supervisor knows that 20 sorties per day are scheduled for the next week and he must conduct some training that will utilize the test station making it unavailable for aircraft support. The present hours of operation for the shop are two 8-hour shifts 5 days per week and the supervisor wishes to maintain these hours of operation. He wants to know how many hours can be devoted to training

```
GERT SIMULATION PROJECT TSCI          BY LOWELL
              DATE  9/ 29/ 1979

     ***RESULTS FOR RUN      ****

  ELAPSED TIME FOR RUN =     126.8158

             **NODE STATISTICS**

 NODE      LABEL          AVE.        NO OF    TYPE OF
                                      OBS.    STATISTICS

  2                       .6661         1.        F
 43                    113.7189        10.        I
 42                     66.5994        10.        I
 41                     55.8276        10.        I
 40                     32.0220        10.        I
 39                      9.9785        10.        I
 38                      3.1411        10.        I

             **NUMBER IN Q-NODE**                        ** WAITING TIME **
                                                            IN QUEUE

 NODE      LABEL          AVE.     MIN.   MAX.    CURRENT      AVERAGE
                                                  NUMBER

 25       EABAO           .2035     0.      9.       0          2.5851
 26       EABBO           .7227     0.     10.       0          9.1654
 27       EDBAO          2.2623     0.     10.       0         25.6899
 28       EDBCO          4.5714     0.     10.       0         57.4645
 29       GDEAO          5.6223     0.     10.       0         83.9812
 30       GDEBO          5.7780     0.     10.       0        111.3194
 46                       .0311     0.      1.       0          3.9487

          **NO. BALKING PER UNIT TIME**

 NODE      LABEL          AVE.

 25       EABAO           .0000
 26       EABBO           .0000
 27       EDBAC           .0000
 28       GDBCO           .0000
 29       GDEAO           .0000
```

Figure 7-3. Elapse Time Statistic Used to Determine Average Repair Time of Backlog

```
GEN,LOWELL,TSDI,9,29,1979,6,0,7,168,12,1,,4*
PAR,1,6,8,0,10,,5*
PAR,2,22,1,,09*
PAR,3,17,1,,30*
PAR,4,6,1,12*
PAR,5,1,1,,5,1,5,,32*
PAR,6,,6,,3,1,0,,17*
PAR,7,,9,,4,1,5,,26*
PAR,8,3,1,1,5,4,5,,9*
PAR,9,1,6,,5,2,0,,46*
PAR,10,2,7,1,3,4,1,,79*
PAR,11,3,6,1,5,5,4,1,0*
PAR,12,2,1,1,0,3,1,,61*
SOU,1,0,1,A*
SOU,58,0,1*
REG,2,1,1*
QUE,3/ACFT,0,24,(10)4*
SEL,8/SORTIES,LNO,FOR,(7)7*
REG,5,1,1,F*
REG,6,1,1*
REG,7,1,1*
REG,8,1,1*
REG,9,1,1*
REG,18,1,1,F,M*
REG,17,1,1,P,M*
REG,20,1,1,F,M*
REG,21,1,1*
REG,22,1,1*
REG,23,1,1,P*
REG,24,1,1,F*
QUE,25/FAPAO,0,,(10)31*
QUE,26/FAPPO,0,,(10)31*
QUE,27/GDRAO,0,,(10)31*
QUE,28/GDFCO,0,,(10)31*
QUE,29/GDFAO,0,,(10)31*
QUE,30/SDFRO,0,,(10)31*
RES,1/TSDI,1,59,47,31*
ALL,31,LRF,1,1,25/32,26/33,27/34,28/35,29/36,30/37*
REG,32,1,1,P*
REG,33,1,1*
REG,38,1,1,P*
REG,35,1,1,F*
REG,34,1,1,F*
REG,37,1,1,F*
STA,37,1,1,,T,1,4*
STA,39,1,1,,T,1,F*
STA,40,1,1,,T,1,4*
STA,41,1,1,,T,1,F*
STA,42,1,1,,T,1,8*
STA,43,1,1,,T,1,F*
FRE,44,,1,1,59,37,71*
REG,45,57,52*
REG,57,1,1*

QUE,58,0,1,(10)59*
ALL,59,LNO,1,1,58/60*
FRE,61,,1,1,59,47,71*
REG,60,1,1,F*
REG,62,1,1*
REG,63,1,1*
QUE,46,0,1,(10)47*
ALL,47,LNO,1,1,45/49*
REG,48,1,1*
FRE,49,,1,1,59,47,31*
VAS,1,1,IN,1*
VAS,2,2,FX,2,3,FX,3,4,FX,4*
VAS,5,2-,CO,1,3-,CO,1,4-,CO,1*
VAS,7,2,FX,2*
VAS,8,3,EX,3*
VAS,9,4,FX,4*
VAS,57,1,,CO,1*
VAS,63,1,CO,0*
ACT,1,1,,,1/ACFT,,,A1,LF,23*
ACT,1,2,,,,,,A1,LF,24*
ACT,2,3*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,5,7,CO,,01,2/FAPOO,,,A2,LF,0*
ACT,5,8,CO,,01,3/GDHOO,,,A3,LF,0*
ACT,5,9,CO,,01,4/GDFOO,,,A4,LF,0*
ACT,5,6*
ACT,7,18*
ACT,7,7*
ACT,8,19*
ACT,8,7*
ACT,9,20*
ACT,9,3*
ACT,6,3*
ACT,18,25,(F),77*
ACT,18,26,(R),04*
ACT,18,21,(P),7*
ACT,19,21,(R),18*
ACT,19,22,(F),82*
ACT,20,21,(F),13*
ACT,20,29,(R),52*
ACT,20,30,(R),35*
ACT,22,23*
ACT,22,24*
ACT,23,27,(F),71*
ACT,23,21,(R),29*
ACT,24,28,(F),29*
ACT,24,21,(R),71*
ACT,32,38,LO,5,10/RPMM,1,,06*
ACT,33,38,LO,6,11/RPMM,1,,94*
ACT,33,39,LO,7,12/RPMM,1*
ACT,34,40,LO,8,13/RPMN,2,,87*

ACT,34,40,LO,9,14/RPMM,2,,18*
ACT,34,40,LO,9,15/RPMM,2,,15*
ACT,35,41,LO,10,16/RPMM,1,,6*
ACT,35,41,LO,9,17/RPMM,1,,2*
ACT,35,41,LO,9,18/RPMM,1,,2*
ACT,36,42,LO,11,19/RPMM,1,,68*
ACT,36,42,LO,12,20/RPMM,1,,12*
ACT,36,42,LO,12,21/RPMM,1,,2*
ACT,37,43,LO,10,22/RPMM,1,,78*
ACT,37,43,LO,9,23/RPMM,1,,12*
ACT,37,43,LO,9,24/RPMM,1,,1*
ACT,38,44*
ACT,39,44*
ACT,40,44*
ACT,41,44*
ACT,42,44*
ACT,43,44*
ACT,44,45*
ACT,45,46*
ACT,48,49,CO,6,*
ACT,49,21*
ACT,56,57*
ACT,57,58,CO,16,5*
ACT,60,61,CO,8,6,,,A1,LF,8*
ACT,60,62,CO,56,7,,,A1,LF,4*
ACT,61,57*
ACT,63,61*
ACT,62,3*
MOD,5,5,62*
MOD,6,62,5*
MOD,7,62,5*
FIN*
@FIN

1.0
```

Figure 7-4. Input Cards for Simulation of Shift Work

during the next week without jeopardizing sortie support or changing the present work schedule.

Adjustment of Simulated Utilization

Simulation of the Q-GERT model design of Chapter IV with parameter set-1 adjusted to generate 20 sorties per day and the clock [nodes 57 through 63] set to allow shop operation as described above as illustrated in figure 7-4 will provide the necessary statistics to estimate the time available for training. Since the method of using the test station on a priority dummy task, to simulate downshifts and weekends, results in increasing the output test station utilization factor, an adjustment must be made to that output statistic to obtain actual test station utilization. The period of simulation for this problem is one week or 168 hours. The work week is 80 hours or .4762 weeks. Computation of an adjusted test station utilization factor is simply

.4762 (mean utilization factor)

where mean utilization is extracted from the summary output as presented in figure 7-5.

An Example Simulation and Results

Twelve simulation runs with model parameters adjusted as described in the preceding paragraph resulted in the output of figure 7-5. Apply- the test station utilization adjustment results in a corrected test station utilization of .3817 which indicates actual utilization of the test station of 30.5 hours. Thus 49.5 hours are available for training.

AVERAGE RESOURCE UTILIZATION

RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.
1	TSD1	.8015	.0577	.0147	12.	.7229	.8938

AVERAGE RESOURCE AVAILABILITY

RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.
1	TSD1	.1985	.0577	.0147	12.	.1062	.2771

Figure 7-5. Average Test Station Utilization

Comparison of Actual Versus Estimated Failures

Purpose of Analysis

Most Air Force resources that support aircraft are allocated based upon an estimate of requirement in the support of flying operations. Each avionic maintenance shop has a specific authorization level for each resource assigned. These resources include test equipment maintenance personnel, and spare LRUs. Individual shop supervisors have almost no control over resource levels authorized but may request additional authorizations upon identification of need and the ability to substantiate the need.

Let's assume that a shop supervisor becomes aware of difficulty in keeping up with the workload of the LRUs from a given aircraft system. He knows that his authorizations of resources to support this system are based on the required sortie rate and estimated mean failure rates. He is also aware that the sortie rate flown in the recent past is within the range used to determine his resource allocations. Every piece of evidence suggests that the problem is due to aircraft failures occurring more frequently than anticipated and the supervisor needs a method by which this hypothesis may be tested.

Simulation with the system failure rate of the system of interest set at the estimated mean sortie between maintenance action rate can be accomplished. Output statistics such as those of figure 7-6 can be used to compute an estimated mean number of LRU failures. Confidence intervals about the mean can be established which define the

```
GERT SIMULATION PROJECT TSDI          BY LOWELL
                    DATE  9/ 29/ 1979


      ***RESULTS FOR RUN    12***

   ELAPSED TIME FOR RUN =     168.0000


           **NODE STATISTICS**
   NODE      LABEL         AVE.        NO OF    TYPE OF
                                        OBS.   STATISTICS

   43                     3.6589         8.        I
   42                     3.8112        18.        I
   41                     3.8051         8.        I
   40                     3.9992         9.        I
   39                                     NO VALUES RECORDED
   38                      .5889         2.        I
```

Figure 7-6. Indication of Simulated LRU Failures

limits of rejection for the hypothesis that a sample mean is from the distribution of the population (failure) mean. The mean for actual realized failures can then be tested against the expected failure mean.

An Example Simulation and Results

The LRU failures of system 74B00 were extracted from the output statistics of 12 simulation runs. The model simulated for this problem had the MSBMA for the 74B00 system set at the rate used to determine support requirements and the number of sorties flown were consistent with original requirements. Computation of mean failures and 95 percent confidence intervals about the mean are accomplished in table 7-2. Results obtained in table 7-2 indicate that if the mean $\overline{X}$, of actual failures is in the interval ($22.14 \leq \overline{X} \leq 27.86$) the supervisor can state with 95 percent confidence that this mean number of failures reflects the estimated mean failure rate. If $\overline{X}$, the mean number of failures realized does not fall in this interval he rejects the hypothesis that the number of failures are representative of the estimated failure rate.

Storage Requirements

Purpose of Analysis

A decision that is often overlooked in avionic maintenance shops is that of allocating space for failed LRUs awaiting maintenance. Temporary storage of most LRUs does not create a problem but there are units such as RADAR antennas that may take several cubic feet of

Table 7-2. Calculation of Mean Number of System 74B00 LRU Failures

No. failures X	$X - \overline{X}$	$(X - \overline{X})^2$
23	-2	4
18	-7	49
30	5	25
26	1	1
22	-3	9
21	-4	16
33	8	64
29	4	16
29	4	16
24	-1	1
20	-5	25
26	1	1
301		227

$\overline{X} = 25$ $n = 12$ $s = 4.54$

$t_{(12,1025)} = 2.179$

storage space and if the average number of these units in the shop is greater than one, lack of adequate storage facilities can create problems. For this reason management, in planning shop layout, must consider the expected number of LRUs awaiting maintenance.

Method of Analysis

Q-GERT output summaries such as figure 7-7 provide a computed average number of units in each queue and the maximum number ever in each queue. The average number in the queue is time dependent and therefore cannot be used for this particular decision. The maximum number in the queue is the statistic one would use to determine storage space requirements since it is most likely that this number is reached predominatly over periods of operational shutdown such as nights and weekends.

If one knows the dimensions of each LRU and the expected maximum number of each LRU awaiting maintenance, it is a simple multiplication to arrive at the storage space required.

		AVERAGE NUMBER IN Q-NODE					**AVERAGE WAITING TIME**			**NUMBER IN Q-NODE**
NODE	LABEL	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	AVE.	STD.DEV.	SD OF AVE	MAX.
[illegible]	[illegible]	[illegible]	[illegible]	.0006	15.9975	15.9985	8.0112	.0543	.0157	16.0000
25	[illegible]	.1715	.2891	.2705	.0000	.7882	6.5187	8.1153	2.3427	2.0000
26	[illegible]	[illegible]	[illegible]	.0009	.0000	.0000	.0000	1.0000	.2887	.0000
27	[illegible]	.2178	[illegible]	.0574	.0000	.9767	5.9533	6.3492	1.8329	2.0000
28	[illegible]	[illegible]	[illegible]	.0514	.0000	.4293	8.0316	10.7084	3.0912	2.0000
29	[illegible]	[illegible]	[illegible]	.0753	.0293	.7521	6.0049	3.7160	1.0727	5.0000
30	[illegible]	.7171	[illegible]	.0619	.0151	.8383	7.7244	6.7710	1.9546	2.0000
55		[illegible]	.0133	.0038	.0124	.0623	1.4201	.4378	.1264	1.0000
56		[illegible]	[illegible]	.0000	.0000	.0000	.0000	1.0445	.3015	.0000

Figure 7-7. Average amd Maximum Number of LRUs in Queues

VIII. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Difficulties exist in the assessment of resource requirements associated with the support of emerging weapon systems. Air Force Test and Evaluation Center analysts require a method to analyze critical questions concerning aircraft logistics support requirements. To be successful, the method must consider the relationship between support resources and aircraft sortie generation. Management alternatives and equipment design options relative to the support system, must be readily evaluated. Evaluation results must be timely and easy to communicate.

The objective of this report is to develop a Q-GERT model that will meet AFTEC analysts' requirements. It has been shown that a Q-GERT network can be used to describe the relationship between aircraft sorties and avionic test station utilization. Networks such as the one shown in chapter IV, provide graphic representation of the system which gives management a clear picture of the overall support process. Simulation of the Q-GERT model, demonstrated the ease in which the network can be used to analyze various questions as posed in chapters VI and VII. The analysis conducted in this report, demonstrated the use of Q-GERT for decision analysis at Command and base level. Model modifications were also accomplished to show the flexibility of the model to analyze various "what if" questions.

Based on the results of Q-GERT networking and analysis accomplished and discussed in this report, it may be concluded that Q-GERT analysis will satisfy AFTEC analysts' needs.

Recommendations

AFTEC plans to use Q-GERT analysis methods to assess F-16 avionic test station support should continue. Such an effort should focus on the extension of the model to include manpower and spare LRUs as constraining resources. Upon completion of the F-16 evaluation, use of Q-GERT should be considered for decision analysis at all levels within the Air Force. The program should be made available to management so that day to day decisions may be made using the same criteria as used for resource allocation.

AD-A091 478 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F/G 15/5
AN ANALYSIS OF AIR FORCE AVIONIC TEST STATION UTILIZATION USING--ETC(U)
DEC 79 J R LOWELL
UNCLASSIFIED AFIT-CI-79-265T NL

2 of 2

END
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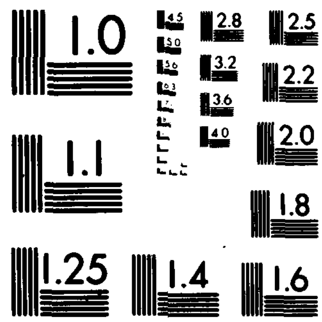

MICROCOPY RESOLUTION TEST CHART

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APPENDIX A

Data Input Description

This appendix includes the input cards required for simulation of the model design of chapter IV. Computer printout of the input data for a successful simulation is presented to aid the interested reader in obtaining a more thorough understanding of this report.

In subsequent pages, the following information is presented:

1. A sequentially numbered list of the input cards used to describe the network model. Comments are printed to the right of selected card inputs to clarity the intended purpose or function of the input.

2. Network description printout which details all Q-GERT functions and the characteristics of each function used in this simulation follows the input cards.

3. Finally, the input cards are again presented in the form that would include diagnostic messages to aid in simulation debugging if system errors were present. The only messages in this example are at the end of the input, and they merely show intended parameter set usage and state that no errors were detected in the input.

```
LOW-24UE(1).TSDI
@RUN,/R LOW20P,83J9970T,AIEE223R,590,100
@SYM PRINTS,,PSPR
@PRT,S LOW-24UE.TSDI
@XQT CS*GERT.C
GEN,LOWELL,TSDI,9,29,1979,6,0,0,168,12,F,,4*
PAR,1,6.4,0,10,.5*                THIS PARAMETER CONTROLS THE NUMBER SORTIES FLOWN
PAR,2,22,1,34*                    THESE PARAMETER SETS ARE MSPMA, FOR SYSTEM FAILURE
PAR,3,17,1,34*
PAR,4,6,1,12*
PAR,5,1.1,.5,1.5,.32*             THESE PARAMETER SETS ARE FOR REPAIR TIMES
PAR,6,.6,.3,1.0,.17*
PAR,7,.9,.4,1.5,.26*
PAR,8,3.1,1.5,4.5,.9*
PAR,9,1.6,.5,2.4,.46*
PAR,10,2.7,1.4,4.1,.73*
PAR,11,3.6,1.8,5.4,1.0*
PAR,12,2.1,1.0,3.1,.61*
SOU,1,0,1,A*                      THIS NODE GENERATES AIRCRAFT
SOU,54,0,1*                       THIS NODE GENERATES THE CLOCK TRANSACTION
REG,2,1,1*
QUE,3/ACFT,0,24,(10)4*            AVAILABLE AIRCRAFT POOL
SEL,4/SORTIES,LNG,POR,(7)3*       SORTIE SELECTION
REG,5,1,1,F*                       DECREMENTS SORTIE COMPLETION
REG,6,1,1*                        NODES 7 THRU 9 INDICATE SYSTEM FAILURE
REG,7,1,1*
REG,8,1,1*
REG,9,1,1*
REG,18,1,1,P,M*                   NODES 18 THRU 24 DETERMINE LRU FAILURES
REG,19,1,1,P,M*
REG,20,1,1,P,M*
REG,21,1,1*
REG,22,1,1*
REG,23,1,1,P*
REG,24,1,1,F*
QUE,25/51BAO,0,,(10)31*           LRU 51BAO AWAITING MAINTENANCE (AWM)
QUE,26/51BBO,0,,(10)31*               51BBO
QUE,27/74BAO,0,,(10)31*               74BAO
QUE,28/74BCO,0,,(10)31*               74BCO
QUE,29/74EAO,0,,(10)31*               74EAO
QUE,30/74EBO,0,,(10)31*               74EBO
RES,1/TSDI,1,59,47,31*            TEST STATION RESOURCE
ALL,31,LNF,1,1,25/32,26/33,27/34,28/35,29/36,30/37*
REG,32,1,1,P*                     NODES 32 THRU 37 DETERMINE REPAIR TIME
REG,33,1,1*
REG,34,1,1,P*
REG,35,1,1,P*
REG,36,1,1,P*
REG,37,1,1,P*
STA,38,1,1,,I,1,C*                NODES 38 THRU 43 COLLECT REPAIR TIME STATS
STA,39,1,1,,I,1,F*
STA,40,1,1,,I,1,B*
STA,41,1,1,,I,1,F*
STA,42,1,1,,I,1,H*
STA,43,1,1,,I,1,C*
FRE,44,,1,1,59,47,31*             FREES TEST STATION
REG,45,52,52*                     COUNTER FOR TEST STATION FAILURE
REG,57,1,1*                       COUNTER FOR DAYS

QUE,58,0,1,(10)59*
ALL,59,LNQ,1,1,58/60*             ALLOCATES TEST STATION FOR NON-WRK SHIFTS
FRE,61,,1,1,59,47,31*             RELEASES TEST STATION AT END OF NON-WRK PERIOD
REG,60,1,1,F*
REG,62,1,1*                       TURNS OFF FLYING
REG,63,1,1*
QUE,46,0,1,(10)47*
ALL,47,LNQ,1,1,46/48*             ALLOCATES TEST STATION FOR TEST STATION FAILURE
REG,48,1,1*
FRE,49,,1,1,59,47,31*             RELEASES TEST STATION AFTER REPAIR
VAS,1,1,IN,1*                     VAS CARDS ASSIGN ATTRIBUTE VALUES
VAS,2,2,EX,2,3,EX,3,4,EX,4*
VAS,5,2,-,CO,1,3,-,CO,1,4,-,CO,1*
VAS,7,2,EX,2*
VAS,8,3,EX,3*
VAS,9,4,EX,4*
VAS,57,1,+,CO,1*
VAS,63,1,CO,3*
ACT,1,1,,,1/ACFT,,,A1.LE.23* ACT CARDS ASSIGN ACTIVITY PARAMETERS
ACT,1,2,,,,,,,A1.GE.24*
ACT,2,3*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,5,7,CO,.01,2/FAPO?,,,A2.LE.0*
ACT,5,8,CO,.01,3/GEPCO,,,A3.LE.0*
ACT,5,9,CO,.01,4/GPEDO,,,A4.LE.0*
```

Figure A-1. Input Data

```
ACT,5,6=
ACT,7,18=
ACT,7,3=
ACT,8,19=
ACT,8,3=
ACT,9,20=
ACT,9,3=
ACT,6,3=
ACT,18,25,(8),.64=
ACT,18,26,(8),.36=
ACT,15,21,(8),.3=
ACT,19,21,(8),.18=
ACT,19,22,(8),.82=
ACT,20,21,(8),.13=
ACT,20,29,(8),.52=
ACT,20,30,(8),.35=
ACT,22,27=
ACT,22,24=
ACT,23,27,(8),.71=
ACT,23,21,(8),.29=
ACT,24,28,(8),.29=
ACT,24,21,(8),.71=
ACT,32,38,LC,5,10/RPMN,1,.06=
ACT,32,33,LO,6,11/RPMN,1,.94=
ACT,33,39,LC,7,12/RPMN,1=
ACT,34,40,LC,8,13/RPMN,2,.67=
```

```
ACT,34,40,LC,9,14/RPMN,2,.18=
ACT,34,40,LO,9,15/RPMN,2,.15=
ACT,35,41,LC,10,16/RPMN,1,.6=
ACT,35,41,LC,9,17/RPMN,1,.2=
ACT,35,41,LO,9,18/RPMN,1,.2=
ACT,36,42,LO,11,19/RPMN,1,.68=
ACT,36,42,LO,12,20/RPMN,1,.12=
ACT,36,42,LO,12,21/RPMN,1,.2=
ACT,37,43,LC,10,22/RPMN,1,.78=
ACT,37,43,LO,9,23/RPMN,1,.12=
ACT,37,43,LO,9,24/RPMN,1,.1=
ACT,38,44=
ACT,39,44=
ACT,40,44=
ACT,41,44=
ACT,42,44=
ACT,43,44=
ACT,44,45=
ACT,45,46=
ACT,48,49,CO,6,=
ACT,49,21=
ACT,54,57=
ACT,57,58,CO,16,5=
ACT,60,61,CO,3,6,,,A1,LF,4=
ACT,60,63,CO,56,7,,,A1,67,4=
ACT,61,57=
ACT,63,61=
ACT,62,3=
MOD,5,5,62=                  MOD CARDS IDENTIFY NODAL MODIFICATION
MOD,6,62,5=
MOD,7,62,8=
FIN=                         INDICATES END OF INPUT
@FIN
```

Figure A-2. Input Data (continued)

```
GERT SIMULATION PROJECT TSDI          BY LOWELL
DATE  9/29/1979   QGERT VERSION 12/30/77

** NETWORK DESCRIPTION **

NUMBER OF STATISTICS NODES------------------------          6
NUMBER OF SINK NODES------------------------------          0
NUMBER OF NODES TO REALIZE THE NETWORK------------          0
THE SIMULATED TIME OF ONE RUN NOT TO EXCEED-----      168.000
NUMBER OF SIMULATIONS REQUESTED-------------------         12
SUMMARY REPORT OPTION-----------------------------          F
TIME FROM WHICH STATISTICS WILL BE KEPT-----------       .000
NUMBER OF ATTRIBUTES PER TRANSACTION--------------          4
```

SOURCE, SINK, REGULAR, AND STAT NODES

NODE	LABEL	INITIAL REQUIREMENT	SUBSEQUENT REQUIREMENT	OUTPUT TYPE	MARK	SINK, STAT OR SOURCE	TYPE OF STATISTICS	CHOICE CRITERION	
1		0	1	A	M	SOU		LAST	0
56		0	1	D	M	SOU		LAST	0
2		1	1	D				LAST	0
3		1	1	F				LAST	0
6		1	1	D				LAST	0
7		1	1	D				LAST	0
8		1	1	D				LAST	0
9		1	1	D				LAST	0
18		1	1	P	M			LAST	0
19		1	1	P	M			LAST	0
20		1	1	P	M			LAST	0
21		1	1	D				LAST	0
22		1	1	D				LAST	0
23		1	1	P				LAST	0
24		1	1	P				LAST	0
32		1	1	F				LAST	0
33		1	1	D				LAST	0
34		1	1	P				LAST	0
35		1	1	P				LAST	0
36		1	1	F				LAST	0
37		1	1	P				LAST	0
38		1	1	D		STA	I	LAST	0
39		1	1	D		STA	I	LAST	0
40		1	1	D		STA	I	LAST	0
41		1	1	D		STA	I	LAST	0
42		1	1	D		STA	I	LAST	0
43		1	1	D		STA	I	LAST	0
45		52	52	D				LAST	0
57		1	1	D				LAST	0
60		1	1	F				LAST	0
62		1	1	D				LAST	0
63		1	1	D				LAST	0
64		1	1	D				LAST	0

Figure A-3. Q-GERT Input Summary

** QUEUE NODES **

NODE	LABEL	INITIAL NO. IN QUEUE	MAXIMUM NO. ALLOWED	OUTPUT TYPE	PRIORITY SCHEME	MAY BLOCK INCIDENT SERVERS	NODE FOR BALKERS	FOLLOWING NODES
3	ACFT	0	24	D	FIFO	NO	0	4
25	EARAO	0	9999	D	FIFO	NO	0	31
26	EARBO	0	9999	D	FIFO	NO	0	31
27	GOBAO	0	9999	D	FIFO	NO	0	31
28	GOBCO	0	9999	D	FIFO	NO	0	31
29	GOEAO	0	9999	D	FIFO	NO	0	31
30	GOEBO	0	9999	D	FIFO	NO	0	31
58		0	1	D	FIFO	NO	0	59
46		0	1	D	FIFO	NO	0	47

** SELECTOR NODES **

NODE	LABEL	SELECTOR RULES (QUEUES)	SELECTOR RULES (SERVERS)	MAY BLOCK INCIDENT SERVERS	NODE FOR BALKERS	Q-NODES ASSOCIATED WITH SELECTOR
4	SORTIES	LNQ	POR	NO	0	3

** RESOURCES **

RESOURCE NUMBER	LABEL	UNITS AVAILABLE	ASSOCIATED ALLOCATE NODES
1	TSDI	1	59 47 31

** RESOURCE ALLOCATE NODES **

NODE	SELECTION RULE	RESOURCE NUMBER	UNITS SEIZED	Q-NODE/ OUTPUT NODE
31	LWF	1	1	25/ 32
				26/ 33
				27/ 34
				28/ 35
				29/ 36
				30/ 37
59	LNQ	1	1	58/ 60
47	LNQ	1	1	46/ 48

Figure A-4. Q-GERT Input Summary (continued)

** FREE RESOURCE NODES **

NODE	OUTPUT TYPE	RESOURCE NUMBER	UNITS FREED	ASSOCIATED ALLOCATE NODES
44	D	1	1	59 47 31
49	D	1	1	59 47 31
61	D	1	1	59 47 31

ATTRIBUTE ASSIGNMENT INFORMATION

NODE NUMBER	ATTRIBUTE NUMBER	DISTRIBUTION TYPE	PARAMETER SPECIFICATION
1	1	IN	1.000
2	2	EX	2.000
2	3	EX	3.000
2	4	EX	4.000
5	2-	CO	1.000
5	3-	CO	1.000
5	4-	CO	1.000
7	2	EX	2.000
8	3	EX	3.000
9	4	EX	4.000
57	1+	CO	1.000
63	1	CO	.000

Figure A-5. Q-GERT Input Summary (continued)

PARAMETER SPECIFICATION

PARAMETER SET	PARAMETERS 1	2	3	4	STREAM
1	6.4000	.0000	10.0000	.5000	10
2	22.0000	1.0000	44.0000	.0000	10
3	17.0000	1.0000	34.0000	.0000	10
4	6.0000	1.0000	12.0000	.0000	10
5	1.1000	.5000	1.5000	.3200	10
6	.6000	.3000	1.0000	.1700	10
7	.9000	.4000	1.5000	.2600	10
8	3.1000	1.5000	4.5000	.9000	10
9	1.6000	.8000	2.4000	.4600	10
10	2.7000	1.4000	4.1000	.7800	10
11	3.6000	1.8000	5.4000	1.0000	10
12	2.1000	1.0000	3.1000	.6100	10

** RANDOM NUMBER SEEDS **

STREAM NUMBER	SEED VALUE	REINITIALIZE (YES/NO)
1	0	NO
2	0	NO
3	0	NO
4	0	NO
5	0	NO
6	0	NO
7	0	NO
8	0	NO
9	0	NO
10	0	NO

Figure A-6. Q-GERT Input Summary (continued)

** ACTIVITY DESCRIPTION **

START NODE	END NODE	FUNCTION TYPE	PARAM SPEC.	ACTIVITY NUMBER	SERVER LABEL	NO. OF SERVERS	PROBABILITY	CONDITIONAL BRANCHING INFORMATION TEST	VARIABLE	RELATION	THRESHOLD
1	1	CO	.000	1		0	1.0000	A	1	.LE.	23.0000
1	2	CO	.000	0		0	1.0000	A	1	.LE.	24.0000
2	3	CO	.000	0		0	1.0000				
4	5	NO	1.000	100		1	1.0000				
4	5	NO	1.000	99		1	1.0000				
4	5	NO	1.000	98		1	1.0000				
4	5	NO	1.000	97		1	1.0000				
4	5	NO	1.000	96		1	1.0000				
4	5	NO	1.000	95		1	1.0000				
4	5	NO	1.000	94		1	1.0000				
4	5	NO	1.000	93		1	1.0000				
5	7	CO	.010	2		0	1.0000	A	2	.LE.	.0000
5	8	CO	.010	3		0	1.0000	A	3	.LE.	.0000
5	9	CO	.010	4		0	1.0000	A	4	.LE.	.0000
5	6	CO	.000	0		0	1.0000	N	5	.R	.0000
6	3	CO	.000	0		0	1.0000				
7	18	CO	.000	0		0	1.0000				
7	3	CO	.000	0		0	1.0000				
8	19	CO	.000	0		0	1.0000				
8	3	CO	.000	0		0	1.0000				
9	20	CO	.000	0		0	1.0000				
9	3	CO	.000	0		0	1.0000				
18	25	CO	.000	0		0	.6600				
18	21	CO	.000	0		0	.3000				
18	26	CO	.000	0		0	.0400				
19	22	CO	.000	0		0	.8200				
19	21	CO	.000	0		0	.1800				
20	29	CO	.000	0		0	.3200				
20	30	CO	.000	0		0	.3500				
20	21	CO	.000	0		0	.1300				
22	23	CO	.000	0		0	1.0000				
22	24	CO	.000	0		0	1.0000				
23	27	CO	.000	0		0	.7100				
23	21	CO	.000	0		0	.2900				
24	21	CO	.000	0		0	.7100				
24	26	CO	.000	0		0	.2900				
32	38	LO	4.000	11		0	.9400				
32	38	LO	5.000	10		0	.0600				
33	39	LO	7.000	12		0	1.0000				
34	40	LO	8.000	13		0	.6700				
34	40	LO	9.000	14		0	.1800				
34	40	LO	7.000	15		0	.1500				
35	41	LO	10.000	16		0	.6000				
35	41	LO	8.000	17		0	.2000				
35	41	LO	9.000	18		0	.2000				
36	42	LO	11.000	19		0	.6800				
36	42	LO	12.000	21		0	.2000				
36	42	LO	13.000	20		0	.1200				
37	43	LO	10.000	22		0	.7600				
37	43	LO	9.000	23		0	.1200				
37	43	LO	9.000	24		0	.1000				
38	44	CO	.000	0		0	1.0000				
39	44	CO	.000	0		0	1.0000				
40	44	CO	.000	0		0	1.0000				
41	44	CO	.000	0		0	1.0000				
42	44	CO	.000	0		0	1.0000				
43	44	CO	.000	0		0	1.0000				
44	45	CO	.000	0		0	1.0000				
45	46	CO	.000	0		0	1.0000				
48	49	CO	4.000	0		0	1.0000				
49	51	CO	.000	0		0	1.0000				
56	57	CO	.000	0		0	1.0000				
57	58	CO	14.000	[illegible]		0	1.0000				

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Figure A-7. Q-GERT Input Summary (continued)

60	61	CO	5.000	6	0	1.0000	A	1	.LE.	4.0000
60	53	CO	56.000	7	0	1.0000	A	1	.GT.	4.0000
61	57	CO	.000	0	0	1.0000				
62	3	CO	.000	0	0	1.0000				
63	61	CO	.000	0	0	1.0000				

NETWORK MODIFICATIONS

I ACTIVITY NUMBER	NODE TO BE REPLACED	REPLACEMENT NODE I
5	5	62
6	62	5
7	62	5

Figure A-8. Q-GERT Input Summary (continued)

```
*** INPUT CARDS ***

GEN,LOWELL,TSDI,9,29,1979,6,C,0,1/P,12,F,,4*
PAR,1,6,4,0,10,.5*                  THIS PARAMETER CONTROLS THE NUMBER SORTIES FLOWN
PAR,2,22,1,44*                      THESE PARAMETER SETS ARE MSBMA, FOR SYSTEM FAILURE
PAR,3,17,1,34*
PAR,4,6,1,12*
PAR,5,1.1,.5,1.5,.32*               THESE PARAMETER SETS ARE FOR REPAIR TIMES
PAR,6,.6,.3,1.0,.17*
PAR,7,.9,.4,1.5,.26*
PAR,8,3.1,1.5,4.5,.9*
PAR,9,1.6,.8,2.4,.46*
PAR,10,2.7,1.4,4.1,.76*
PAR,11,3.6,1.8,5.4,1.0*
PAR,12,2.1,1.0,3.1,.61*
SOU,1,0,1,A*                        THIS NODE GENERATES AIRCRAFT
SOU,56,0,1*                         THIS NODE GENERATES THE CLOCK TRANSACTION
REG,2,1,1*
QUE,3/ACFT,0,24,(10)4*              AVAILABLE AIRCRAFT POOL
SEL,4/SORTIES,LNQ,POR,(7)3*         SORTIE SELECTION
REG,5,1,1,F*                         DECREMENTS SORTIE COMPLETION
REG,6,1,1*                          NODES 7 THRU 9 INDICATE SYSTEM FAILURE
REG,7,1,1*
REG,8,1,1*
REG,9,1,1*
REG,18,1,1,P,M*                     NODES 18 THRU 24 DETERMINE LRU FAILURES
REG,19,1,1,P,M*
REG,20,1,1,P,M*
REG,21,1,1*
REG,22,1,1*
REG,23,1,1,P*
REG,24,1,1,P*
QUE,25/EABAO,0,,(10)31*             LRU 51BAO AWAITING MAINTENANCE (AWM)
QUE,26/EABBO,0,,(10)31*                 51BBO
QUE,27/GDBAO,0,,(10)31*                 74BAO
QUE,28/GDBCO,0,,(10)31*                 74BCO
QUE,29/GDEAO,0,,(10)31*                 74EAO
QUE,30/GDEBO,0,,(10)31*                 74EBO
RES,1/TSDI,1,59,47,31*              TEST STATION RESOURCE
ALL,31,LWF,1,1,25/32,26/33,27/34,28/35,29/36,30/37*
REG,32,1,1,P*                       NODES 32 THRU 37 DETERMINE REPAIR TIME
REG,33,1,1*
REG,34,1,1,P*
REG,35,1,1,P*
REG,36,1,1,P*
REG,37,1,1,P*
STA,38,1,1,,I,1,8*                  NODES 38 THRU 43 COLLECT REPAIR TIME STATS
STA,39,1,1,,I,1,8*
STA,40,1,1,,I,1,8*
STA,41,1,1,,I,1,8*
STA,42,1,1,,I,1,6*
STA,43,1,1,,I,1,6*
FRE,44,,1,1,59,47,31*               FREES TEST STATION
REG,45,52,52*                       COUNTER FOR TEST STATION FAILURE
REG,57,1,1*                         COUNTER FOR DAYS
QUE,58,0,1,(10)59*
```

Figure A-9. Q-GERT Source Listing

```
ALL,59,LNO,1,1,58/60*         ALLOCATES TEST STATION FOR NON-WRK SHIFTS
FRE,61,,1,1,59,47,31*         RELEASES TEST STATION AT END OF NON-WRK PERIOD
REG,60,1,1,F*
REG,62,1,1*                   TURNS OFF FLYING
REG,63,1,1*
QUE,46,0,1,(10)47*
ALL,47,LNO,1,1,46/48*         ALLOCATES TEST STATION FOR TEST STATION FAILURE
REG,48,1,1*
FRE,49,,1,1,59,47,31*         RELEASES TEST STATION AFTER REPAIR
VAS,1,1,IN,1*                 VAS CARDS ASSIGN ATTRIBUTE VALUES
VAS,2,2,EX,2,3,EX,3,4,EX,4*
VAS,5,2-,CO,1,3-,CO,1,4-,CO,1*
VAS,7,2,EX,2*
VAS,8,3,EX,3*
VAS,9,4,EX,4*
VAS,57,1+,CO,1*
VAS,63,1,CO,0*
ACT,1,1,,,1/ACFT,,,A1,LF,23*  ACT CARDS ASSIGN ACTIVITY PARAMETERS
ACT,1,2,,,,,,A1,LF,24*
ACT,2,3*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,4,5,NO,1*
ACT,5,7,CO,.01,2/E4ROO,,,A2,LF,0*
ACT,5,8,CO,.01,3/GDPOO,,,A3,LE,0*
ACT,5,9,CO,.01,4/GDFOO,,,A4,LE,0*
ACT,5,6*
ACT,7,18*
ACT,7,3*
ACT,8,19*
ACT,8,3*
ACT,9,20*
ACT,9,3*
ACT,6,3*
ACT,16,25,(F).66*
ACT,18,26,(9).04*
ACT,18,21,(F).3*
ACT,19,21,(P).18*
ACT,19,22,(P).82*
ACT,20,21,(9).13*
ACT,20,29,(F).52*
ACT,20,30,(9).35*
ACT,22,23*
ACT,22,24*
ACT,23,27,(R).71*
ACT,23,21,(9).29*
ACT,24,28,(P).29*
ACT,24,21,(9).71*
ACT,32,36,LO,5,10/RPMN,1,.06*
ACT,32,38,LO,6,11/RPMN,1,.94*
ACT,33,39,LO,7,12/RPMN,1*
ACT,34,40,LO,8,13/RPMN,2,.67*
ACT,34,40,LO,9,14/RPMN,2,.18*
```

Figure A-10. Q-GERT Source Listing (continued)

```
ACT,34,40,LO,9,15/RPMN,2,,.15*
ACT,35,41,LO,10,16/RPMN,1,,.6*
ACT,35,41,LO,9,17/RPMN,1,,.2*
ACT,35,41,LO,9,18/RPMN,1,,.2*
ACT,36,42,LO,11,19/RPMN,1,,.68*
ACT,36,42,LO,12,20/RPMN,1,,.12*
ACT,36,42,LO,12,21/RPMN,1,,.2*
ACT,37,43,LO,10,22/RPMN,1,,.78*
ACT,37,43,LO,9,23/RPMN,1,,.12*
ACT,37,43,LO,9,24/RPMN,1,,.1*
ACT,38,44*
ACT,39,44*
ACT,40,44*
ACT,41,44*
ACT,42,44*
ACT,43,44*
ACT,44,45*
ACT,45,46*
ACT,48,49,CO,6,*
ACT,49,21*
ACT,56,57*
ACT,57,58,CO,16,5*
ACT,60,61,CO,P,6,,,A1,LE,4*
ACT,60,63,CO,56,7,,,A1,GT,4*
ACT,61,57*
ACT,63,61*
ACT,62,3*
MOD,5,5,62*                              MOD CARDS IDENTIFY NODAL MODIFICATION
MOD,6,62,5*
MOD,7,62,5*
FIN*                                     INDICATES END OF INPUT
        PARAMETER SET     9    WAS ONLY MODIFIED ONCE
        PARAMETER SET     9    WAS ONLY MODIFIED ONCE
        PARAMETER SET     9    WAS ONLY MODIFIED ONCE
        PARAMETER SET    12    WAS ONLY MODIFIED ONCE
        PARAMETER SET    10    WAS ONLY MODIFIED ONCE
        PARAMETER SET     9    WAS ONLY MODIFIED ONCE
        PARAMETER SET     9    WAS ONLY MODIFIED ONCE
*** NO ERRORS DETECTED IN INPUT DATA ***
*** EXECUTION WILL BE ATTEMPTED ***
```

Figure A-11. Q-GERT Source Listing (continued)

APPENDIX B

Summary Report Description

This appendix includes an example Q-GERT summary report. The summary presented is for a simulation of the model design of chapter IV for 168 hours (one week) with a requirement of 20 sorties flown per day.

Most of the data items in the report are self explanatory but a discussion of selected element headings is included. Data elements that are discussed have a number next to them that corresponds to the following:

1. ***RESULTS FOR RUN 1***; identifies the run number for which the subsequent statistics were collected,

2. ELAPSED TIME FOR RUN = ; indicates the simulation time units required to complete the run;

3. **NODE STATISTICS**; provides data collected at statistics nodes. The average column for each node may be a release time, a delay time, or an interval of time depending on the type statistic requested. The number of observations column indicates the number of node releases that occurred during the simulation run.

4. **NUMBER IN Q-NODE** and **WAITING TIME IN QUEUE** are statistics associated with the number of transactions that must wait in the queue and the time spent in waiting. The average number in the queue is a time weighted statistic and the maximum number in the queue is absolute.

5. NODE and TRANSACTION PASSAGES ; list the node numbers and indicate the number of releases of each node during simulation.

6. **FINAL RESULTS FOR 12 SIMULATIONS**; is an accumulation of the statistics collected in each simulation run. The output format is similar to that of the individual run statistics but the averages are computed on the average from each simulation run. The observation columns reflect the number of simulation runs included in the computations.

7. STAT HISTOGRAMS FOR NODE 43; provides a histogram of the statistics collected at node-43. OBSV FREQ is the number of observations in the range of the cell defined in the column at the far right. RELA and CUML FREQ are the relative and cumulative frequencies of the observations. These frequency statistics may be used to estimate the probability distribution of the variable measured by the statistics node.

```
GERT SIMULATION PROJECT TSDI          BY LOWELL
                         DATE  9/ 29/ 1979

     ***RESULTS FOR RUN      1***  (1)

   ELAPSED TIME FOR RUN =     168.0000  (2)

          **NODE STATISTICS**  (3)
   NODE      LABEL         AVE.        NO OF     TYPE OF
                                       OPS.     STATISTICS

   43                     1.9890        2.         I
   42                     4.4000        5.         I
   41                     4.9554        3.         I
   40                     4.6717        4.         I
   39                                  NO VALUES RECORDED
   38                     ?.0558        3.         I

          **NUMBER IN Q-NODE**  (4)              (4) ** WAITING TIME **
                                                         IN QUEUE

   NODE     LABEL        AVE.      MIN.   MAX.    CURRENT       AVERAGE
                                                   NUMBER

    3       ACFT       15.2998     0.     16.       16          11.7886
   25       EAPAO        .0451     0.      1.        0           2.5250
   26       EARPO        .0000     0.      0.        0            .0000
   27       EDPAO        .0362     0.      1.        0           1.5213
   28       GDPCO        .1329     0.      1.        0           7.4424
   29       GDEAO        .0303     0.      1.        0           1.0167
   30       GDEPO        .3174     0.      1.        1          17.7729
   58                    .0547     0.      1.        0           1.8369
   46                    .0000     0.      0.        0            .0000

          **SERVER UTILIZATION**

  SERVER     LABEL    NO. PARALLEL    AVE.          MAX. IDLE            MAX. BUSY
                        SERVERS               (TIME OR SERVERS)   (TIME OR SERVERS)

  100                      1        1.0000           .0000             168.0000
   99                      1        1.0000           .0000             168.0000
   98                      1        1.0000           .0000             168.0000
   97                      1        1.0000           .0000             168.0000
   96                      1        1.0000           .0000             168.0000
   95                      1        1.0000           .0000             168.0000
   94                      1        1.0000           .0000             168.0000
   93                      1        1.0000           .0000             168.0000
```

Figure B-1. Output Summary

NO. WAITING PER UNIT TIME

NODE	LABEL	AVE.
3	RCPT	.0000
48		.0000
46		.0000

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	TSDI	1	.723	1	0	.277	1

NODE	TRANSACTION PASSAGES
1	24
2	24
3	212
4	212
5	100
6	80
7	4
8	6
9	10
18	4
19	6
20	10
21	7
22	5
23	5
24	5
25	3
26	0
27	4
28	3
29	5
30	2
31	17
32	3
34	4
35	3
36	5
37	2
38	3
40	4
41	3
42	5
43	2
44	17
46	0
56	1
57	5
58	5
59	5
60	5
61	4
62	174

S

PRINTOUT OF ONGOING ACTIVITIES
AT 168.00

ACTIVITY END TIME	END NODE	ACTIVITY NUMBER
168.14	5	99
170.10	5	95
170.38	5	94
170.39	5	96
170.49	5	93
170.76	5	98
171.06	5	97
172.02	5	100
177.18	43	7

Figure B-2. Output Summary (continued)

GERT SIMULATION PROJECT TSDI   BY LOWELL
DATE 9/ 29/ 1979

FINAL RESULTS FOR 12 SIMULATIONS 6

AVERAGE NODE STATISTICS

NODE	LABEL	PROBABILITY	AVE.	STD.DEV.	SD OF AVE	NO OF OBS.	MIN.	MAX.	STAT TYPE
43		1.0000	5.4416	1.7729	.5118	12.	1.9890	7.9317	I
42		1.0000	6.2003	2.0692	.5973	12.	4.3825	10.6148	I
41		1.0000	8.5323	5.1099	1.4751	12.	2.4775	18.0123	I
40		1.0000	4.3728	2.9051	.8386	12.	1.7035	11.8489	I
39			NO VALUES RECORDED						
38		.9167	5.7690	6.4941	1.9580	11.	.5720	21.2768	I

		AVERAGE NUMBER IN Q-NODE					**AVERAGE WAITING TIME**			**NUMBER IN Q-NODE**
NODE	LABEL	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	AVE.	STD.DEV.	SD OF AVE	MAX.
3	ARF1	15.9985	.0033	.0010	15.9979	15.9988	11.6734	.0580	.0167	16.0000
25	EARRO	.0569	.0694	.0200	.0000	.2246	4.8023	6.4252	1.8548	2.0000
26	FARRO	.0000	.0000	.0000	.0000	.0000	.0000	1.0445	.3015	.0000
27	SPEAO	.0983	.1236	.0357	.0000	.3190	4.7384	7.4528	2.1514	1.0000
28	RORRO	.1472	.1202	.0347	.0000	.3480	9.0095	6.6008	1.9055	2.0000
29	RPERO	.1862	.1400	.0404	.0303	.3943	4.4544	4.0102	1.1577	3.0000
30	RPERO	.1223	.0971	.0280	.0128	.3174	4.5039	4.4096	1.2729	3.0000
44		.0301	.0110	.0032	.0072	.0547	1.0105	.3690	.1065	1.0000
46		.0000	.0000	.0000	.0000	.0000	.0000	1.0445	.3015	.0000

			AVERAGE SERVER UTILIZATION						**EXTREME VALUES**	
SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY
100		1	1.0000	.0000	.0000	12.	1.0000	1.0000	.0000	168.0000
99		1	1.0000	.0000	.0000	12.	1.0000	1.0000	.0000	168.0000
98		1	1.0000	.0000	.0000	12.	1.0000	1.0000	.0000	168.0000
97		1	1.0000	.0000	.0000	12.	1.0000	1.0000	.0000	168.0000
96		1	1.0000	.0000	.0000	12.	1.0000	1.0000	.0000	168.0000
95		1	1.0000	.0000	.0000	12.	1.0000	1.0000	.0000	168.0000
94		1	1.0000	.0000	.0000	12.	1.0000	1.0000	.0000	168.0000
93		1	1.0000	.0000	.0000	12.	1.0000	1.0000	.0000	168.0000

Figure B-3. Output Summary (continued)

AVERAGE NO. BALKING PER UNIT TIME

NODE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.
3	ACFT	.0000	.0000	.0000	12.	.0000	.0000
SP		.0000	.0000	.0000	12.	.0000	.0000
NA		.0000	.0000	.0000	12.	.0000	.0000

AVERAGE RESOURCE UTILIZATION **NUMBER OF RESOURCES**

RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	MAX.
1	ISPT	.8015	.0577	.0167	12.	.7229	.8938	1.

AVERAGE RESOURCE AVAILABILITY **NUMBER OF RESOURCES**

RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	MAX.
1	ISPT	.1985	.0577	.0167	12.	.1062	.2771	1.

Figure B-4. Output Summary (continued)

STAT HISTOGRAM FOR NODE #3 7

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER BOUND OF CELL
0	.000	.000	1.00
0	.000	.000	1.10
0	.000	.000	1.20
0	.000	.000	1.30
0	.000	.000	1.40
0	.000	.000	1.50
0	.000	.000	1.60
0	.000	.000	1.70
0	.000	.000	1.80
0	.000	.000	1.90
1	.083	.083	2.00
0	.000	.083	2.10
0	.000	.083	2.20
0	.000	.083	2.30
0	.000	.083	2.40
0	.000	.083	2.50
0	.000	.083	2.60
0	.000	.083	2.70
0	.000	.083	2.80
11	.917	1.000	+INF
TOTAL 12			

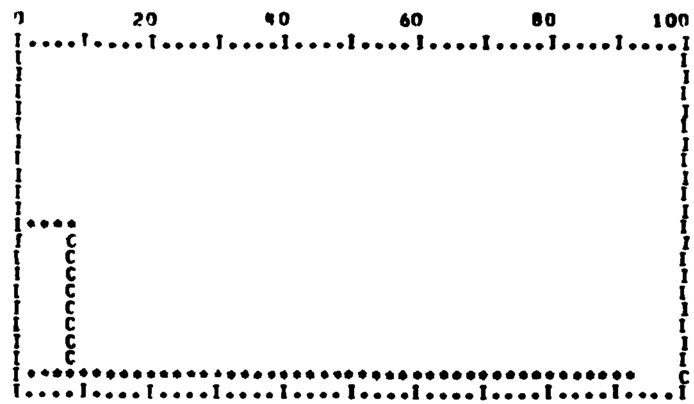

Figure B-5. Output Summary (continued)

```
I   STAT HISTOGRAM FOR NODE   #2

OBSV     RELA     CUML        UPPER        0         20        40        60        80        100
FREQ     FREQ     FREQ     BOUND OF CELL   I....I....I....I....I....I....I....I....I....I....I
   0     .000     .000          .00        I                                                  I
   0     .000     .000          .50        I                                                  I
   0     .000     .000         1.00        I                                                  I
   0     .000     .000         1.50        I                                                  I
   0     .000     .000         2.00        I                                                  I
   0     .000     .000         2.50        I                                                  I
   0     .000     .000         3.00        I                                                  I
   0     .000     .000         3.50        I                                                  I
   0     .000     .000         4.00        I                                                  I
   3     .250     .250         4.50        I*************                                     I
   1     .083     .333         5.00        I****            C                                 I
   3     .250     .583         5.50        I*************                C                    I
   0     .000     .583         6.00        I                             C                    I
   1     .083     .667         6.50        I****                             C                I
   1     .083     .750         7.00        I****                                 C            I
   1     .083     .833         7.50        I****                                     C        I
   0     .000     .833         8.00        I                                         C        I
   0     .000     .833         8.50        I                                         C        I
   0     .000     .833         9.00        I                                         C        I
   2     .167    1.000         +INF        I********                                          C
                                           I....I....I....I....I....I....I....I....I....I....I
        ---
TOTAL    12
```

Figure B-6. Output Summary (continued)

```
I   STAT HISTOGRAM FOR NODE    41

  OBSV      RELA      CUML        UPPER          0         20        40        60        80        100
  FREQ      FREQ      FREQ     BOUND OF CELL     I....I....I....I....I....I....I....I....I....I....I
     0      .000      .000             .00       I                                                  I
     0      .000      .000            1.00       I                                                  I
     0      .000      .000            2.00       I                                                  I
     1      .083      .083            3.00       I****                                              I
     2      .167      .250            4.00       I********    C                                     I
     1      .083      .333            5.00       I****            C                                 I
     0      .000      .333            6.00       I                C                                 I
     2      .167      .500            7.00       I********                C                         I
     0      .000      .500            8.00       I                        C                         I
     0      .000      .500            9.00       I                        C                         I
     3      .250      .750           10.00       I************                        C             I
     0      .000      .750           11.00       I                                    C             I
     1      .083      .833           12.00       I****                                     C        I
     0      .000      .833           13.00       I                                         C        I
     0      .000      .833           14.00       I                                         C        I
     0      .000      .833           15.00       I                                         C        I
     0      .000      .833           16.00       I                                         C        I
     0      .000      .833           17.00       I                                         C        I
     1      .083      .917           18.00       I****                                         C    I
     1      .083     1.000            +INF       I****                                              C
                                                 I....I....I....I....I....I....I....I....I....I....I
           ---
TOTAL       12
```

Figure B-7. Output Summary (continued)

1 STAT HISTOGRAM FOR NODE 40

OBSV FREQ	RELA FREQ	CUML FREQ	UPPER BOUND OF CELL
0	.000	.000	.00
0	.000	.000	.50
0	.000	.000	1.00
0	.000	.000	1.50
2	.167	.167	2.00
0	.000	.167	2.50
3	.250	.417	3.00
1	.083	.500	3.50
0	.000	.500	4.00
3	.250	.750	4.50
1	.083	.833	5.00
0	.000	.833	5.50
0	.000	.833	6.00
0	.000	.833	6.50
0	.000	.833	7.00
0	.000	.833	7.50
0	.000	.833	8.00
1	.083	.917	8.50
0	.000	.917	9.00
1	.083	1.000	+INF
TOTAL 12			

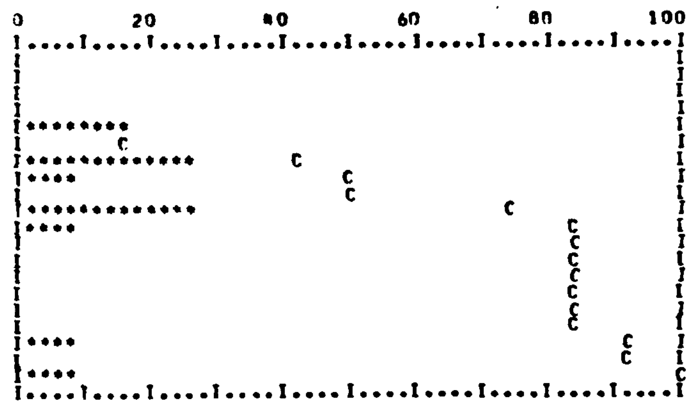

Figure B-8. Output Summary (continued)

```
I   STAT HISTOGRAM FOR NODE    38

  OBSV      RELA      CUML         UPPER         0        20        40        60        80       100
  FREQ      FREQ      FREQ     BOUND OF CELL     I....I....I....I....I....I....I....I....I....I....I
    0       .000      .000          .00          I                                                   I
    3       .273      .273         1.00          I**************                                     I
    1       .091      .364         2.00          I*****             C                                I
    0       .000      .364         3.00          I                  C                                I
    1       .091      .455         4.00          I*****                  C                           I
    2       .182      .636         5.00          I**********                      C                  I
    1       .091      .727         6.00          I*****                               C              I
    0       .000      .727         7.00          I                                    C              I
    0       .000      .727         8.00          I                                    C              I
    0       .000      .727         9.00          I                                    C              I
    1       .091      .818        10.00          I*****                                    C         I
    0       .000      .818        11.00          I                                         C         I
    0       .000      .818        12.00          I                                         C         I
    0       .000      .818        13.00          I                                         C         I
    1       .091      .909        14.00          I*****                                        C     I
    0       .000      .909        15.00          I                                             C     I
    0       .000      .909        16.00          I                                             C     I
    0       .000      .909        17.00          I                                             C     I
    0       .000      .909        18.00          I                                             C     I
    1       .091     1.000         +INF          I*****                                              C
                                                 I....I....I....I....I....I....I....I....I....I....I
   ---
TOTAL   11
```

Figure B-9. Output Summary (continued)

BIOGRAPHICAL SKETCH

James Russell Lowell was born April 9, 1942 in Minneapolis, Minnesota. He graduated from Corona High School, Corona, California in 1960 and entered the USAF. Attending classes at the University of Arizona and the University of Maryland, he became eligible for and was selected to participate in the Air Force Airmans Education and Commissioning Program. He completed his Bachelor of Science Degree at New Mexico State University in 1973 and received his commission as a second lieutenant in the United States Air Force.

In August 1978, Captain Lowell entered Arizona State University, sponsored by the Air Force Institute of Technology, to pursue a Masters of Science Degree in Engineering.

Captain Lowell is a member of Alpha Pi Mu (industrial engineering honor society) and the American Institute of Industrial Engineers - Student Chapter.